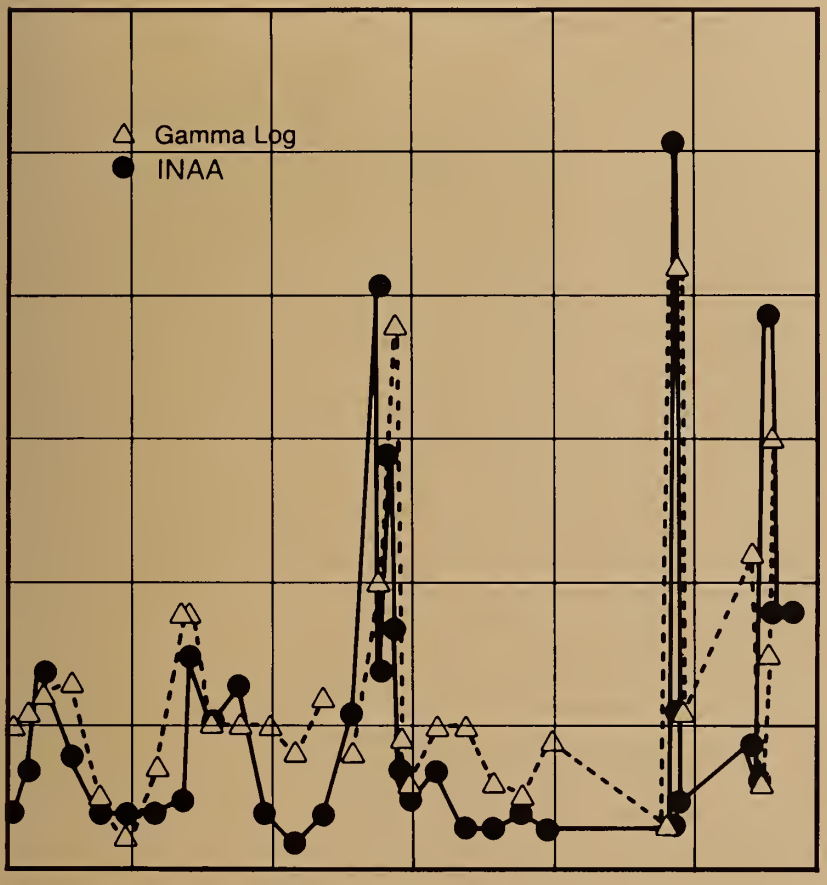
Geol Survey

NATURAL BACKGROUND RADIATION IN THE PROPOSED ILLINOIS SSC SITING AREA



R. H. Gilkeson
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C. R. Gendron

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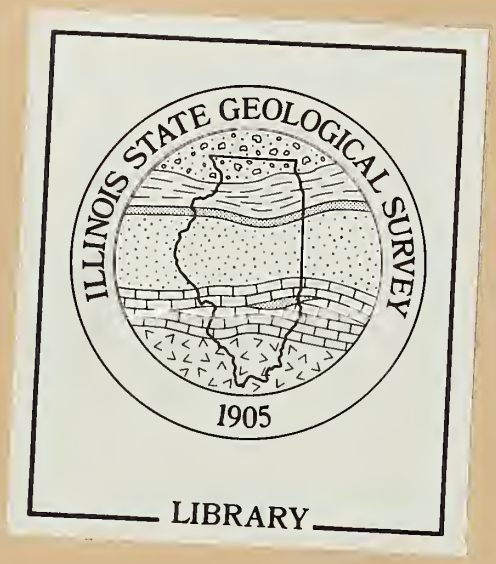
ENVIRONMENTAL GEOLOGY NOTES 127

Department of Energy and Natural Resources
ILLINOIS STATE GEOLOGICAL SURVEY



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NATURAL BACKGROUND RADIATION IN THE PROPOSED ILLINOIS SSC SITING AREA

R. H. Gilkeson*
R. A. Cahill
C. R. Gendron

ILLINOIS STATE GEOLOGICAL SURVEY
Morris W. Leighton, Chief

Natural Resources Building
615 East Peabody Drive
Champaign, Illinois 61820

1988

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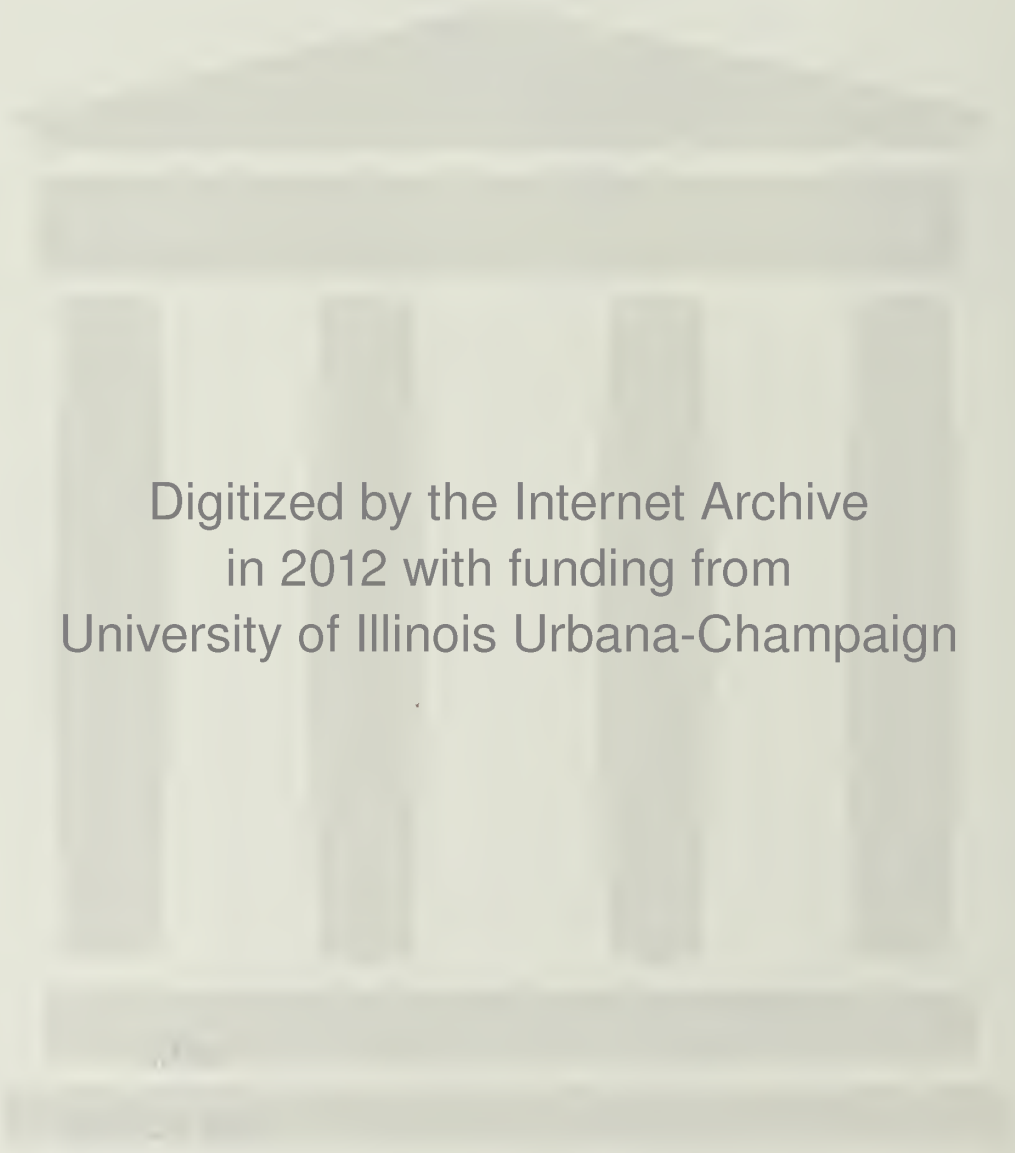
ILLINOIS STATE GEOLOGICAL SURVEY

* Roy F. Weston, Inc., West Chester, PA



CONTENTS

TABLES

FIGURES

EXECUTIVE SUMMARY

This report provides background information on the concentration of significant radionuclides in the rocks, soils, and groundwater at the proposed Illinois site for the Superconducting Super Collider. No attempt has been made to evaluate the health risks or hazards of radioactivity. That issue is beyond the scope of this report.

A large set of regional and national data exists on the natural radioactivity of soils, bedrock, and groundwater in the proposed siting area. An evaluation of this data indicates that the total natural radioactivity environment in the proposed siting area has low background values and poses no problems for construction and operation of the Superconducting Super Collider in Illinois.

The major source of radiation exposure to humans is from natural radioactivity in the environment. A rigorous characterization of these natural radiation sources is important for siting the Superconducting Super Collider (SSC). People interact with the natural environment in different ways as a function of occupation and life style. Therefore, an accurate understanding of the radiation dose delivered to humans requires both broad and discrete characterization of all radioactive components in the environment.

The major terrestrial sources of background radioactivity are radioactive elements that are members of the decay series of the two primordial radioactive elements, uranium-238 and thorium-232, and the primordial radioactive element, potassium-40. These radioactive elements are distributed in soils (principally unlithified glacial sediments), bedrock, and groundwaters of the proposed study area for the SSC.

The surficial soils (glacial sediments) are the source for one significant component of the natural radioactive environment—gamma radiation at land surface. An airborne total gamma radiation survey flown over the Chicago region (including the proposed siting area) in 1959 determined a mean value for the terrestrial absorbed dose rate in air of 42 mrad/yr. For comparison, the average for all gamma radiometric surveys in the middle United States is 46 mrad/yr with a range of 35 to 75 mrad/yr.

The U.S. Department of Energy (DOE) conducted a national airborne gamma-ray spectrometer survey for the Aurora Quadrangle, which includes the SSC study area. The data set from the survey can be interpreted to calculate concentration of potassium, equivalent uranium, and equivalent thorium for surficial materials in the proposed siting area. Potassium ranges from 0.6 to 1.4 percent, equivalent uranium ranges from 0.6 to 3.0 ppm, and equivalent thorium ranges from 5.5 to 7.0 ppm. These concentrations are low compared with average values measured in surficial materials around the world.

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The surficial glacial sediments are the major source for radon in indoor atmospheres. Concentrations of radon in groundwater resources in the proposed siting area are low and of no environmental concern. The U.S. Environmental Protection Agency (U.S. EPA) has issued an action guideline of 4 pCi/L for radon in indoor atmospheres. National surveys are underway to characterize regional variations in indoor radon concentrations. Analysis of data for the eight-county region of northeastern Illinois (including the SSC siting area) determined an arithmetic mean of 2.3 pCi/L, a value significantly lower than either the national mean of 3.64 pCi/L or the U.S. EPA action guideline. The average radioactive element concentrations for the major lithologic groups as measured by two separate techniques fall below the state and national levels. Clean sandstones and dolomites have very low concentrations of radioactive elements. The tunnel is to be constructed in the Galena and Platteville Dolomite. Even the highest concentrations of radioactive elements, which occur in shales and shaly sandstones, are relatively low and of no environmental concern. Bedrock in the proposed siting area does not contain materials of high radioactivity, such as coal measure or uraniferous deposits. Rock debris generated during construction of shafts or the tunnel does not pose a radioactivity hazard that requires special handling or disposal.

Underground structures require monitoring to ensure that atmospheric radon concentrations do not exceed occupational levels. The low concentrations of uranium and thorium in the dolomite and the low concentrations of radon in groundwater from these rocks are evidence that atmospheric radon concentrations will be readily controlled. Conventional ventilation required for other reasons will likely reduce radon concentrations to low values.

The U.S. EPA is in the process of setting drinking water standards for radium, uranium, and radon. Groundwater resources are important for domestic and public water supplies in the SSC siting area. The majority of domestic supplies and many public supplies are obtained from wells that are 100 to 300 feet deep. These wells are finished in sand and gravel deposits or in dolomite bedrock. An abundant database indicates that groundwaters from these aquifers have low concentrations of radioactive elements and are in compliance with drinking water standards.

Wells more than 1000 feet deep that produce groundwater from confined sandstones in the Cambrian and Ordovician bedrock are an important source of public water supplies in the siting area. In the proposed siting area, this source of groundwater has low values of uranium and radon, but it commonly exceeds the U.S. EPA interim standard of 5.0 pCi/L for dissolved radium. Concentrations are less than 10 pCi/L throughout much of the siting area but do exceed 20 pCi/L locally. The U.S. EPA has received expert testimony that the standard is conservative and that concentrations present throughout most of the siting area are of no concern for public health. Evidence also shows that conventional water treatment methods (such as lime-slurry softening and ion-exchange resins) efficiently reduce radium concentrations to levels below that stated by the drinking water standard.

INTRODUCTION

This report provides background information on the concentration of the significant radionuclides that occur in the rocks, soils, and groundwater at the proposed Illinois site for the Superconducting Super Collider. No attempt has been made to evaluate the health risks or hazards of radioactivity. That issue is beyond the scope of this report. The authors believe that the issues of radiation protection and safety are better handled by the Illinois Department of Nuclear Safety and the National Council on Radiation Protection and Measurements (see references in the glossary).

The major source of radiation exposure to humans is radiation from natural sources in the environment. A rigorous characterization of these natural radiation sources is important for siting the Superconducting Super Collider (SSC). Issues addressed in the study include

- pre-operational natural background radiation dosage to the public in the siting region;
- identification of any changes that may occur in the natural background of radioactivity during construction of the SSC;
- assessment of the dosage that natural radioactive elements present to workers during construction and operation of the facility.

To accurately assess dosage, researchers must evaluate the natural radioactivity environment in a variety of ways because people interact with the environment according to occupation and life style. Therefore, a complete understanding of the radiation dosage delivered to human beings requires both broad and discrete characterization of radioactive components in the natural environment.

The natural radiation environment is classified as terrestrial and extraterrestrial (cosmic) sources. A broad treatment of extraterrestrial radiation is adequate for characterization of dose in the siting region, since extraterrestrial radiation varies with elevation. The terrestrial sources, however, must be characterized both collectively and discretely because of the different ways in which people interact with terrestrial sources of radiation.

EXTRATERRESTRIAL RADIATION

Cosmic radiation consists of primary particles of extraterrestrial origin as well as secondary particles generated by interactions of the primary particles with the atmosphere. The secondary particles are referred to as cosmogenic radionuclides. The cosmic radiation dose typically contributes about 30 to 50 percent of the total whole-body dose from all external environmental radiation (NCRP, 1975).

The assessment of the cosmic radiation dose requires knowledge of the composition, energy spectrum, and angular distribution of the cosmic ray particle flux; the spatial and the temporal variations of the cosmic intensity; and the distribution of the population by altitude and

latitude. Existing information in these areas is sufficient to permit a reasonable estimate of the average population exposure to cosmic radiation. The estimate of radiation exposure can therefore be based on the average elevation of the proposed SSC siting area.

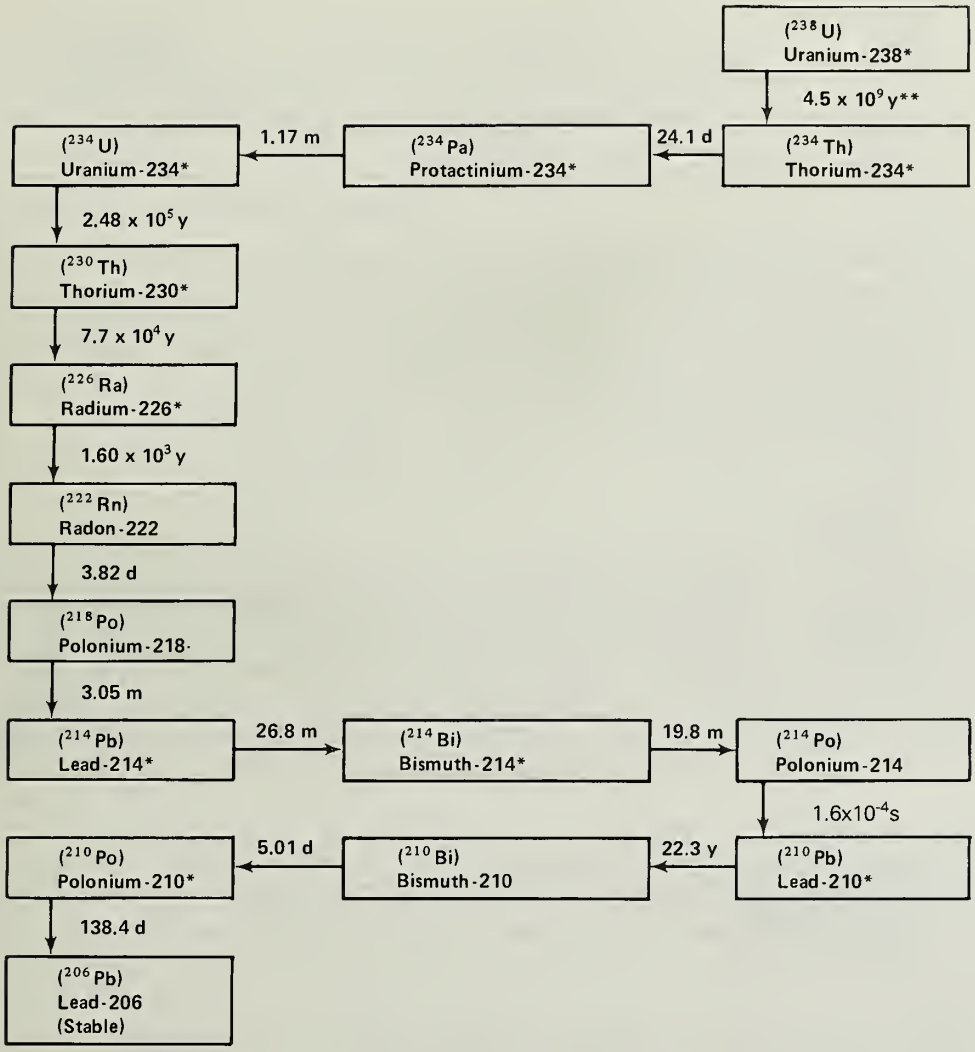
By using data on cosmic-ray particle flux densities and absorbed dose rates in air, scientists can infer an altitude profile of the long-term average cosmic-ray dose in the lower atmosphere (NCRP, 1975). The ground-level elevation in the proposed SSC siting area varies from 600 to 950 feet above mean sea level. Using an average elevation of 775 feet (325 meters), the NCRP calculated the whole-body (gonadal) dose to be 28 mrem/yr. The dose was calculated for a depth of 5 centimeters in a 30-centimeter cross section of tissue, and a 10-percent reduction was applied to account for the effect of structural shielding. The average annual cosmic radiation dose to the entire U.S. population was estimated to be 28 mrem/yr (Oakley and Goldin, 1975), while the average annual doses at sea level and in Denver, Colorado (elevation 1600 meters), were estimated to be 26 mrem/yr and 50 mrem/yr, respectively. (Radiation terms are included in the glossary.)

The major production of cosmogenic radionuclides is through the interaction of cosmic rays with atmospheric gases. The four cosmogenic radionuclides that contribute a measurable dose are carbon-14, hydrogen-3 (tritium), sodium-22, and beryllium-7. The geographic and vertical production rates of these nuclides in the atmosphere have been measured (Young et al., 1970a) or estimated from cosmic-ray data (Young et al., 1970b).

Cosmogenic radionuclides contribute very little of the population dose from natural background radiation. The average dose equivalent rate to the whole body from cosmogenic radionuclides for a standard adult in the United States is estimated to be 0.7 mrem/yr, with essentially all of the dose arising from carbon-14 (NCRP, 1975).

TERRESTRIAL RADIATION

The exposure of humans to terrestrial radiation arises from radionuclides that are distributed in the geologic materials of the earth or have been transferred from the earth to the atmosphere or hydrosphere. Water (as groundwater or soil moisture) plays an important role in the transport of radionuclides in geologic materials. The significant natural sources are potassium-40 and the decay series of the two primordial radionuclides, thorium-232 and uranium-238. The radioactive decay series of uranium-238 and thorium-232 are shown in figures 1 and 2, which present the half-life and the mode of disintegration (alpha, beta, or gamma) for series nuclides. A third primordial radionuclide, uranium-235, has a mass abundance ratio to uranium-238 of only 0.0073. Therefore, the uranium-235 (actinium) decay series is not significant for natural radiation exposure (NCRP, 1975).

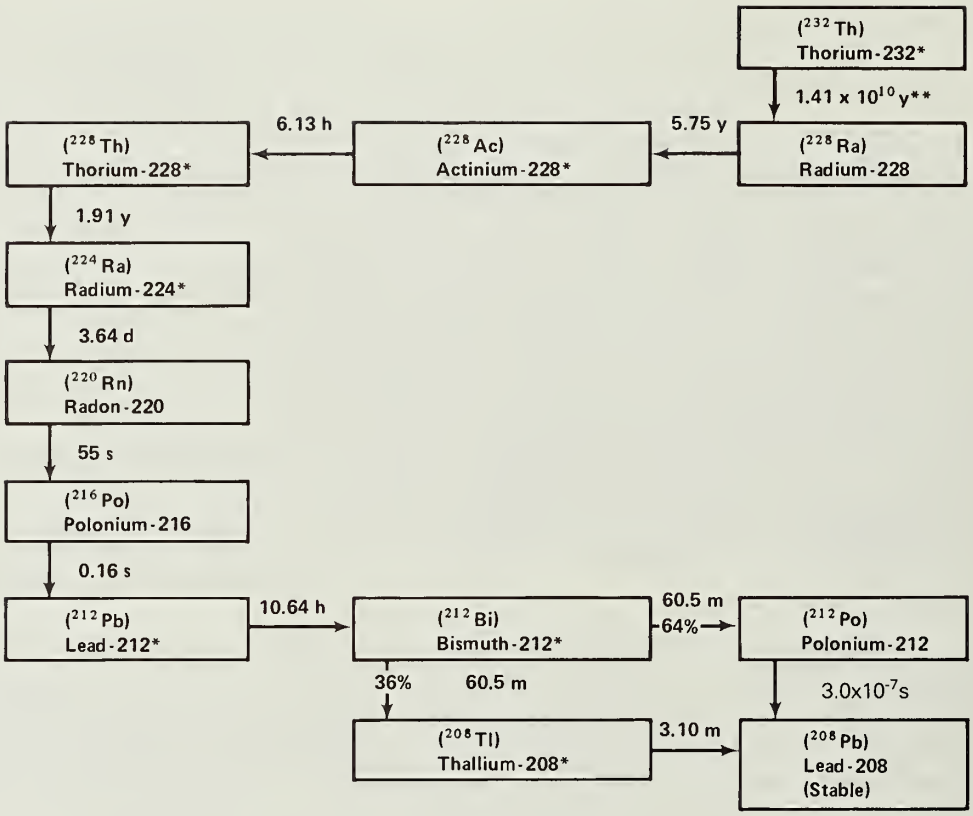


Note: Vertical direction represents alpha decay; horizontal direction represents beta decay.

* Also gamma emitters

** Times shown are half-lives: y = years; d = days; h = hours; m = minutes: s = seconds

Figure 1 Radioactive decay series of uranium-238 (from Gilkeson et al., 1983).



Note: Vertical direction represents alpha decay; horizontal direction represents beta decay.
* Also gamma emitters
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Figure 2 Radioactive decay series of thorium-232 (from Gilkeson et al., 1983).

Potassium-40, with a half-life of 1.26×10^9 years, decays directly into the stable elements, calcium-40 and argon-40. Both beta and gamma radiation are produced in the disintegration. The isotopic abundance of potassium-40 is 0.0118 percent of total potassium.

Gamma Radiation at Ground Surface

The naturally occurring radionuclides in near-surface geologic materials collectively supply a significant component of the background radiation exposure to the population. At ground surface, the significant exposure to humans comes from the two terrestrial sources of gamma radiation: radionuclides in the shallow geologic materials and radon daughters present in the atmosphere (NCRP, 1975). The external radiation from alpha and beta emitters in the ground or in the air does not contribute a significant absorbed dose (NCRP, 1975).

Two total gamma radiometric surveys have been flown over the SSC study area. These aerial radiological measuring system (ARMS) surveys provided information on the natural background radiation in the region surrounding nuclear facilities (Burson, 1974). Instruments measured the total flux of gamma radiation with energies greater than 50 thousand electron volts (KeV). Despite the lack of discrete analysis of the gamma radiation, the data gathered in these surveys are valuable in assessing the total natural gamma background radiation from terrestrial sources.

The first radiometric survey was flown in 1959 over the Chicago region as one of several surveys (ARMS 1) performed by the U.S. Geological Survey. The second survey, flown over the Dresden nuclear plant in 1971, was one of several aerial surveys in the vicinity of nuclear power plants conducted by the consulting firm E.G. and G., Inc. Most surveys were done before the plants were operating; and in the others, no reactor-produced radionuclides were detected (NCRP, 1975). The surveys were flown at a height of approximately 500 feet on flight lines that were spaced one mile apart. Oakley (1972) analyzed the radiometric data from ARMS to calculate a whole-body absorbed dose rate for the Chicago region (figure 3). The mean value for the region was 4.8 μrad/hr (42 mrad/yr). For comparison, figure 3 shows the calculated absorbed dose rates in other ARMS 1 areas.

Burson (1974) correlated the data from radiometric surveys flown over nuclear plants. The results for the Dresden area (53 mrad/yr) are compared with dose rates calculated for other surveys over reactor areas in figure 4. The majority of these surveys were pre-operational. Applying a housing factor of 0.80 (Oakley, 1972) and a gonadal and bone marrow screening factor of 0.80 (Bennett, 1970), and assuming a quality factor of unity, Oakley calculated the gonadal or bone marrow dose equivalent rate for the Dresden area measurements to be 34 mrem/yr.

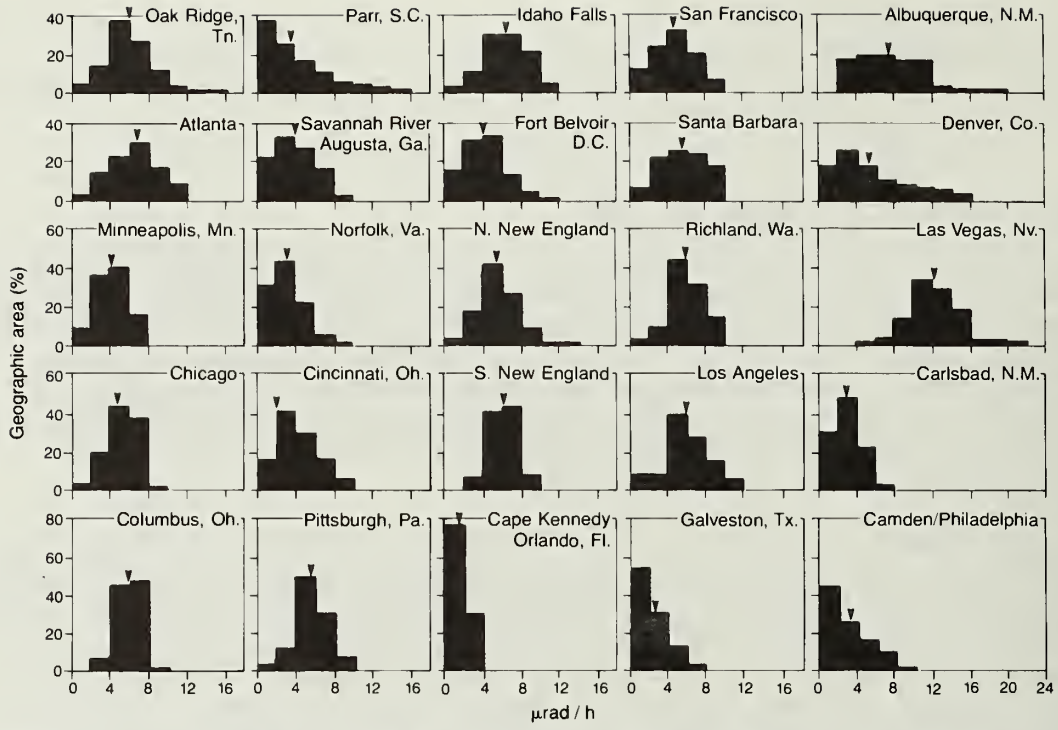

Figure 3 Whole-body absorbed dose rates in ARMS areas (from Oakley, 1972). Mean denoted by arrow.

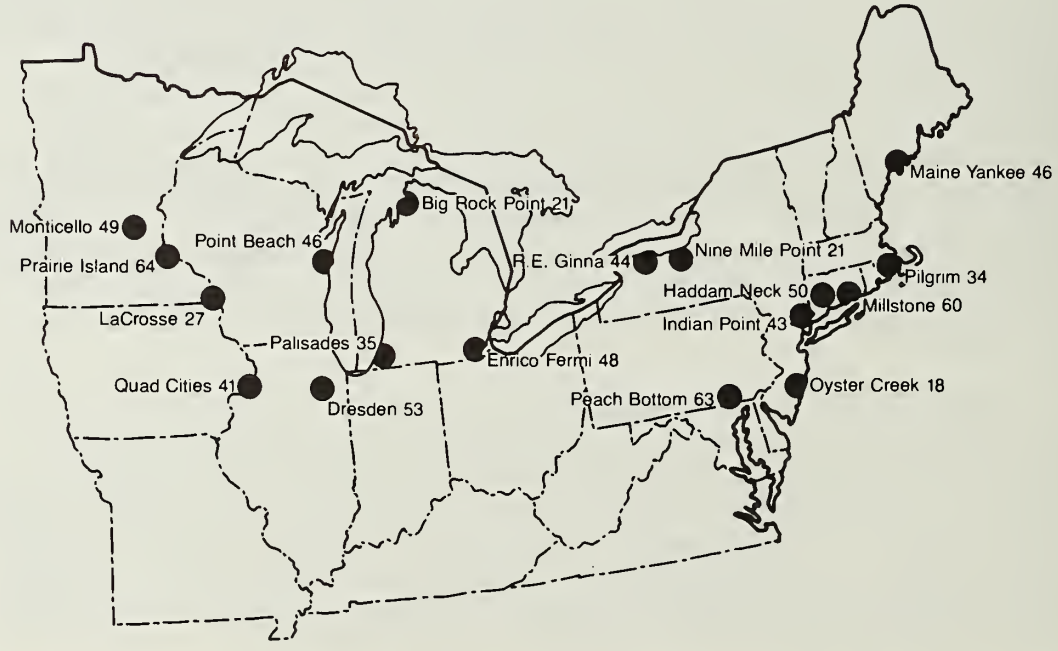

Figure 4 Aerial surveys over nuclear reactor sites. Numbers indicate mean absorbed dose rates in air in mrad/yr (from Burson, 1974).

Natural Radioactivity of Surficial Geologic Materials in the Proposed Siting Region

An accurate assessment of the radioactive content in the surface geologic materials in the SSC siting area is essential to the determination of possible health hazards due to exposure to these materials. A national airborne spectral gamma radiation survey conducted by the U.S. Department of Energy (DOE) provided information on the natural radioactivity of surficial geologic materials. Although the aerial survey directly measured the natural radioactivity of material to a depth of only 30 to 60 centimeters, it has often been interpreted to characterize the distribution of natural radioactivity in geologic materials to a depth of several meters. A measurement program was conducted to evaluate natural radioactivity in deep geological materials in the proposed siting area. This program included measurements with an in situ spectral gamma ray (SGR) geophysical tool in three boreholes, and laboratory analysis of rock chips from the three boreholes by instrumental neutron activation analysis (INAA).

The U.S. DOE conducted the airborne gamma ray spectrometer survey over Illinois as part of its National Uranium Resource Evaluation Program (NURE). The survey methods and results for the region of Illinois that includes the SSC study area are presented in a DOE report (1981a) for the Aurora Quadrangle. The location of the Aurora Quadrangle and the SSC study area are shown in figure 5.

For the Aurora Quadrangle, gamma ray spectral data were gathered on east-west traverse lines flown at six-mile intervals, and on north-south tie lines flown at 18-mile intervals. The mean flight altitude above land surface was 393 feet, and mean flight velocity was 96.6 miles per hour. Altitude attenuation coefficients were used to correct measured count rates at any elevation to a reference elevation of 400 feet. The airborne detector measured gamma radiation from geologic materials and any other materials present on land surface or buried at shallow depth. Because of the strong attenuation of gamma rays in materials, the measurement recorded by the airborne spectrometer is generally from materials present to depths of only one to two feet below land surface.

In the airborne spectrometer survey, potassium-40 is directly measured by a single clear peak at 1.46 MeV (million electron volts). By contrast, thorium-232 and uranium-238 do not have any clear distinct peaks. The concentrations of these isotopes are interpreted by measuring the activities of the daughter nuclides, bismuth-214 (for uranium-238) and thallium-208 (for thorium-232). Because uranium and thorium concentrations are not measured directly, they are referenced as equivalent concentrations. A fundamental assumption in calculating the concentrations of uranium and thorium is that a state of equilibrium exists between original and derived nuclides. The uranium-238 and thorium-232 decay series are shown in figures 1 and 2.

Interpretation maps (figs. 6-9) of potassium, uranium and thorium variation in the SSC study area were taken from the NURE report. The maps are pseudo contour plots showing variation of total gamma radiation,

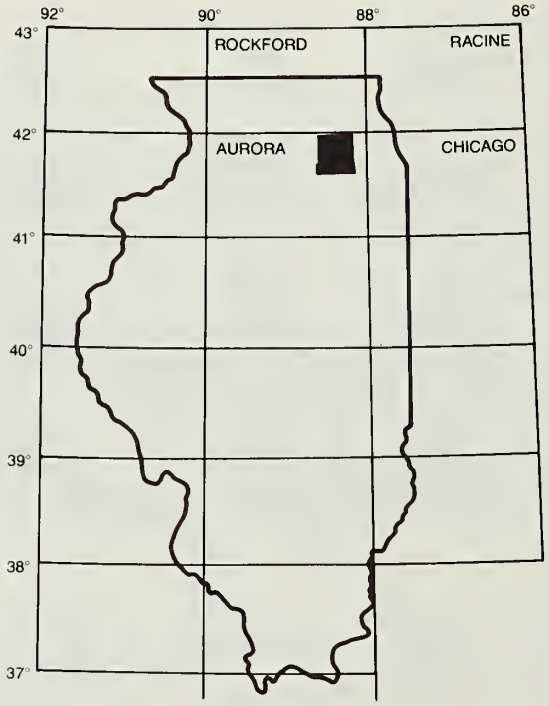

Figure 5 Location of Aurora, Rockford, Chicago, and Racine Quadrangles and the 36-township SSC study area within the Aurora Quadrangle.

Table 1. Explanation of pseudo contours

Pseudo contour number	(fig.6) Total gamma radiation (counts/s)	(fig. 7) Potassium (%)	(fig. 8) Equivalent thorium (ppm)	(fig. 9) Equivalent uranium (ppm)
0	750-800	0	0	0
	800-850	0 - .1	0 - .5	0 - .2
1	850-900	.1 - .2	.5 - 1.0	.2 - .4
	900-1000	.2 - .3	1.0 - 1.5	.4 - .6
2	1000-1050	.3 - .4	1.5 - 2.0	.6 - .8
	1050-1100	.4 - .5	2.0 - 2.5	.8 - 1.0
3	1100-1150	.5 - .6	2.5 - 3.0	1.0 - 1.2
	1150-1200	.6 - .7	3.0 - 3.5	1.2 - 1.4
4	1200-1250	.7 - .8	3.5 - 4.0	1.4 - 1.6
	1250-1300	.8 - .9	4.0 - 4.5	1.6 - 1.8
5	1300-1350	.9 - 1.0	4.5 - 5.0	1.8 - 2.0
	1350-1400	1.0 - 1.1	5.0 - 5.5	2.0 - 2.2
6	1400-1450	1.1 - 1.2	5.5 - 6.0	2.2 - 2.4
	1450-1500	1.2 - 1.3	6.0 - 6.5	2.4 - 2.6
7	1500-1550	1.3 - 1.4	6.5 - 7.0	2.6 - 2.8
	1550-1600			2.8 - 3.0

potassium, equivalent uranium, and equivalent thorium. Table 1 presents scales for converting the numbers on pseudo contour plots into concentrations. The total potassium concentration was calculated from the isotopic abundance of potassium-40 (0.0118%). Uranium and thorium concentrations are expressed as equivalent uranium and equivalent thorium to indicate that measurements were on daughter isotopes with an assumption of equilibrium.

The total count rates of gamma radiation in the SSC study area (fig. 6) range from 750 to 1550 counts per second. Through most of the area, total gamma radiation ranges from 1100 to 1350 counts/s. The lowest counts (750 to 1100 counts/s) occur in an area along the Fox River valley. Lower radioactivity values for all parameters were measured in the valley and probably are due to shielding of gamma radiation by water. The highest counts (1400 to 1550 counts/s) occur in a locality in the southwestern part of the study area.

Figures 7, 8, and 9 present pseudo contour maps for potassium, equivalent thorium, and equivalent uranium. The concentrations of potassium-40, equivalent uranium, and equivalent thorium are derived by converting counts/s data using the detection efficiencies calculated for the measurement system. These three concentrations do not directly correspond to real geochemical data. The locations of significant anomalies are discussed later, but the regional distribution of pseudo contours is not considered in detail.

The range of potassium concentrations in the map area (fig. 7) is from 0.6 to 1.4 percent. Through much of the area, concentrations range uniformly from 0.9 to 1.2 percent. The lowest concentrations are in the region of the Fox River valley; the highest (1.2% to 1.3%) are clustered in the southwestern, southeastern, northwestern, and northeastern parts of the study area.

The concentration of equivalent thorium in the surficial geologic materials in the SSC study area (fig. 8) are from 2.5 to 7.0 parts per million (ppm). Concentrations vary from 3.5 to 6.0 ppm throughout most of the area. The lowest concentrations were measured along the Fox River valley. Values are generally higher in the western part of the study area than in the eastern, with the highest concentrations (5.5 to 7.0 ppm) clustered in the southwest.

The NURE survey determined equivalent uranium concentrations in the surficial geologic materials in the study area (fig. 9) to range from 0.6 to 3.0 ppm. Concentrations through most of the area vary from 1.0 to 2.0 ppm. A north-south zone of higher concentration occurs in the western half of the study area, with highest concentrations (2.2 to 3.0 ppm) present to the south. Relatively lower equivalent uranium concentrations occur in the Fox River valley.

Within the SSC study area, the concentrations of the three radioactive elements are relatively low. They are comparable to values that occur

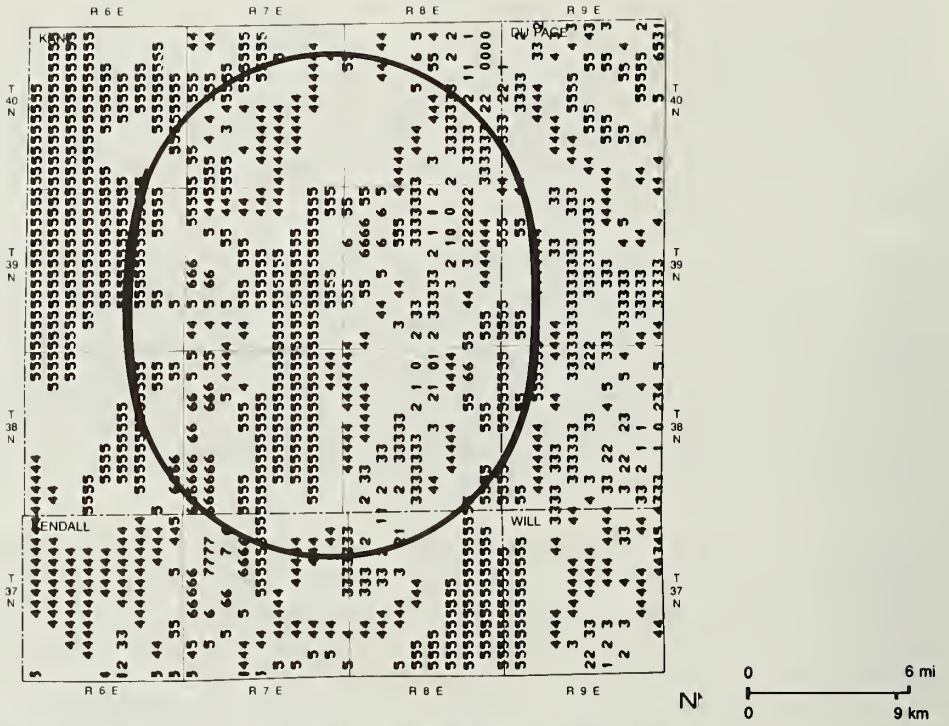

Figure 6 A pseudo contour plot of the variation in total count of gamma radiation from surficial geologic materials in the SSC study area (modified from U.S. DOE, 1981a). Table 1 presents a scale for converting pseudo contour numbers to counts per second of gamma radiation.

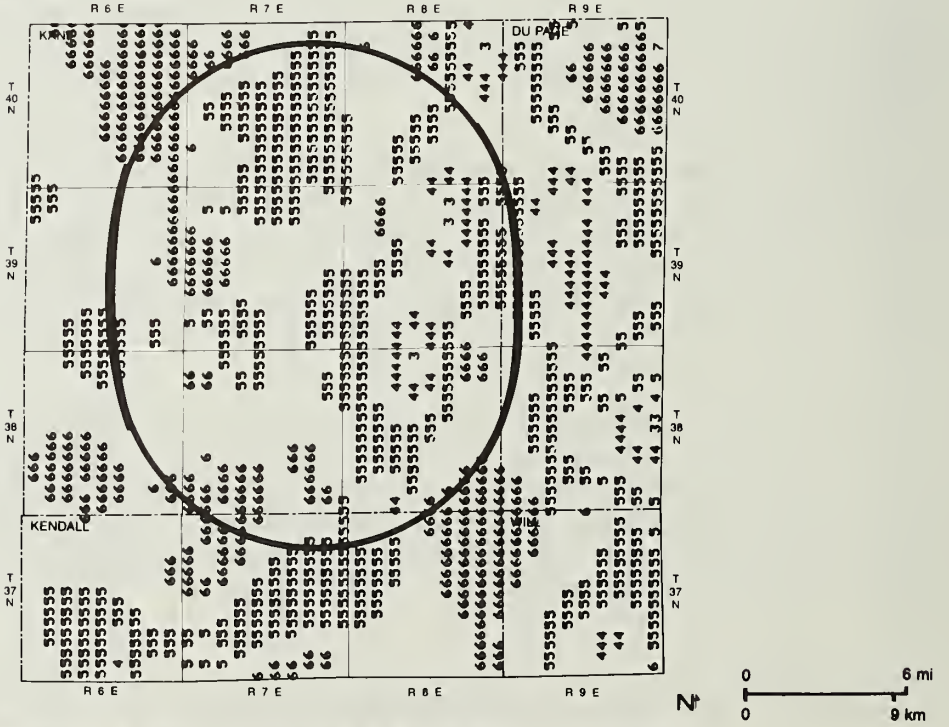

Figure 7 A pseudo contour plot of the variation in concentration of potassium in surficial geologic material in the SSC study area (modified from U.S. DOE, 1981a). Table 1 presents a scale for converting the pseudo contour numbers to concentrations in percent of total potassium.

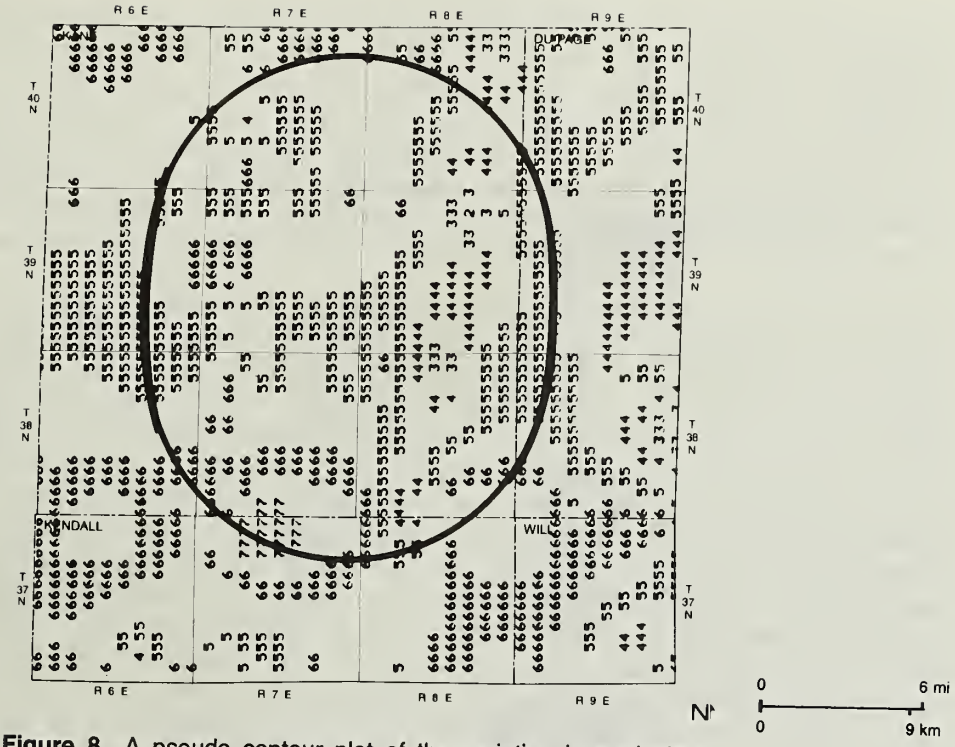

Figure 8 A pseudo contour plot of the variation in equivalent thorium in surficial geologic materials in the SSC study area (modified from U.S. DOE, 1981a). Table 1 presents a scale for converting the pseudo contour numbers to concentrations in parts per million of equivalent thorium.

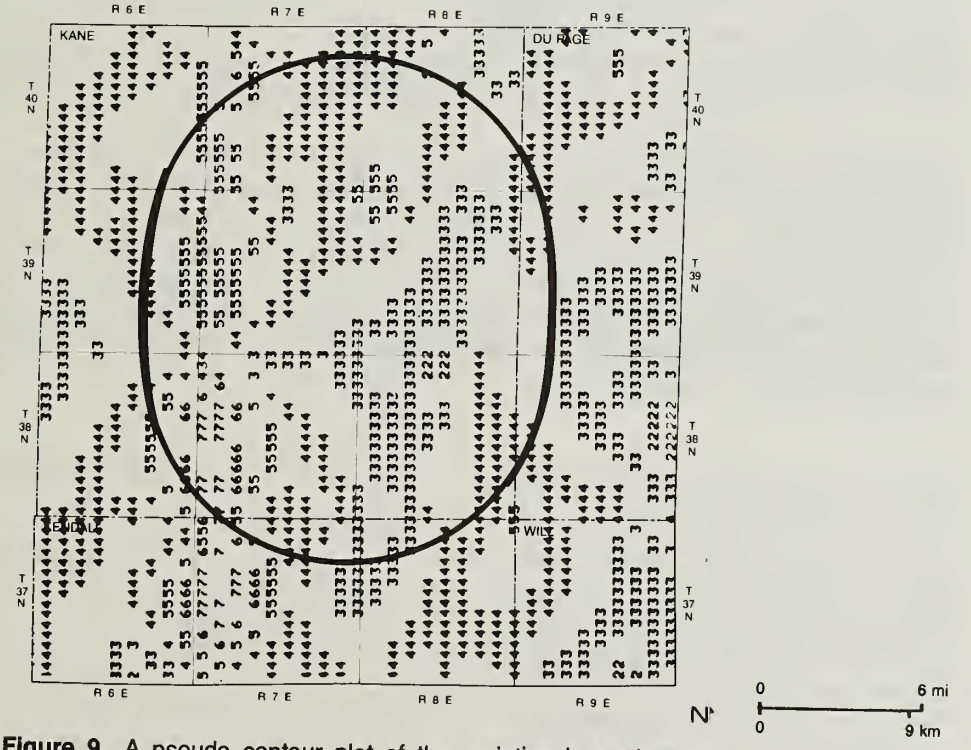

Figure 9 A pseudo contour plot of the variation in equivalent uranium in surficial geologic materials in the SSC study area (modified from U.S. DOE, 1981a). Table 1 presents a scale for converting the pseudo contour numbers to concentrations in parts per million of equivalent uranium.

throughout the Aurora Quadrangle, and to concentrations measured by NURE surveys flown over the Rockford Quadrangle to the north and the Chicago Quadrangle to the east. For example, the average concentrations determined for the Chicago Quadrangle are 1.0 percent for potassium, 3.6 ppm for equivalent thorium, and 1.5 ppm for equivalent uranium (DOE, 1981b). The average concentrations for radioactive elements in surface materials in northeastern Illinois are relatively low when compared with average values measured in surficial materials (soils) worldwide (see table 3).

The goal of the NURE program was regional reconnaissance to determine areas of anomalously high concentrations of uranium; however, the anomalies generated in the automatic reduction of data can arise from conditions other than actual accumulations of radioactive minerals. Within the Aurora Quadrangle, the NURE program defined 23 anomalies. Only one of these anomalies is located within the SSC study area. The location of this anomaly is shown on the equivalent uranium map (fig. 9). Superposition of the flight line that detected the anomaly over a topographic base map centered the anomaly at a rural cemetery located in the SW1/4 of the SW1/4 of Section 32, T38N, R7E, Kane County. The cemetery is at an elevation of 710 feet above mean sea level and on a small knoll of anomalously high relief. The knoll is 35 to 50 feet higher than the surrounding landscape. The U.S. Department of Agriculture soil map for Kane County describes the surficial materials as well-drained loam overlying calcareous loam till. The relatively high equivalent uranium activities measured in the aircraft may reflect a combination of factors: the local relief, gamma radiation from uranium in granitic grave markers, and higher flux of gamma radiation due to the well-drained soils on the knoll in contrast to water-saturated soils lower on the landscape. Environmental monitoring in the vicinity of Argonne National Laboratory (Golchert, Duffy, and Sedlet, 1983) has documented that granitic markers are a source of anomalously high gamma radiation in cemeteries.

Twenty soil samples collected on or near the Fermi National Accelerator Laboratory were analyzed for thorium-232, uranium-238, and potassium-40 (Jobst, 1981). The thorium-232 concentration ranged from 3 to 11.3 ppm with an average of 9.4 ppm. The uranium-238 concentration ranged from 1.0 to 3.7 ppm with an average of 2.8 ppm. The potassium-40 concentration ranged from 6.6 to 21 pCi/g with an average of 16.4 pCi/g. The concentrations expressed in μR/h are 2.9, 1.8, and 2.9 for the individual radionuclides, respectively, or a combined exposure of 7.6 μR/h.

Natural Radioactivity of Bedrock in the Proposed Siting Region

An accurate assessment of the radioactive content in the bedrock materials in the SSC siting area is essential in determining possible health hazards due to exposure to these materials. In situ measurements using a spectral gamma ray geophysical tool were taken in three boreholes drilled in the proposed siting area. The locations of the boreholes are shown in figure 10. The holes were drilled with air rotary methods so that representative samples of the bedrock units could be collected for analysis by instrumental neutron activation in the laboratory.

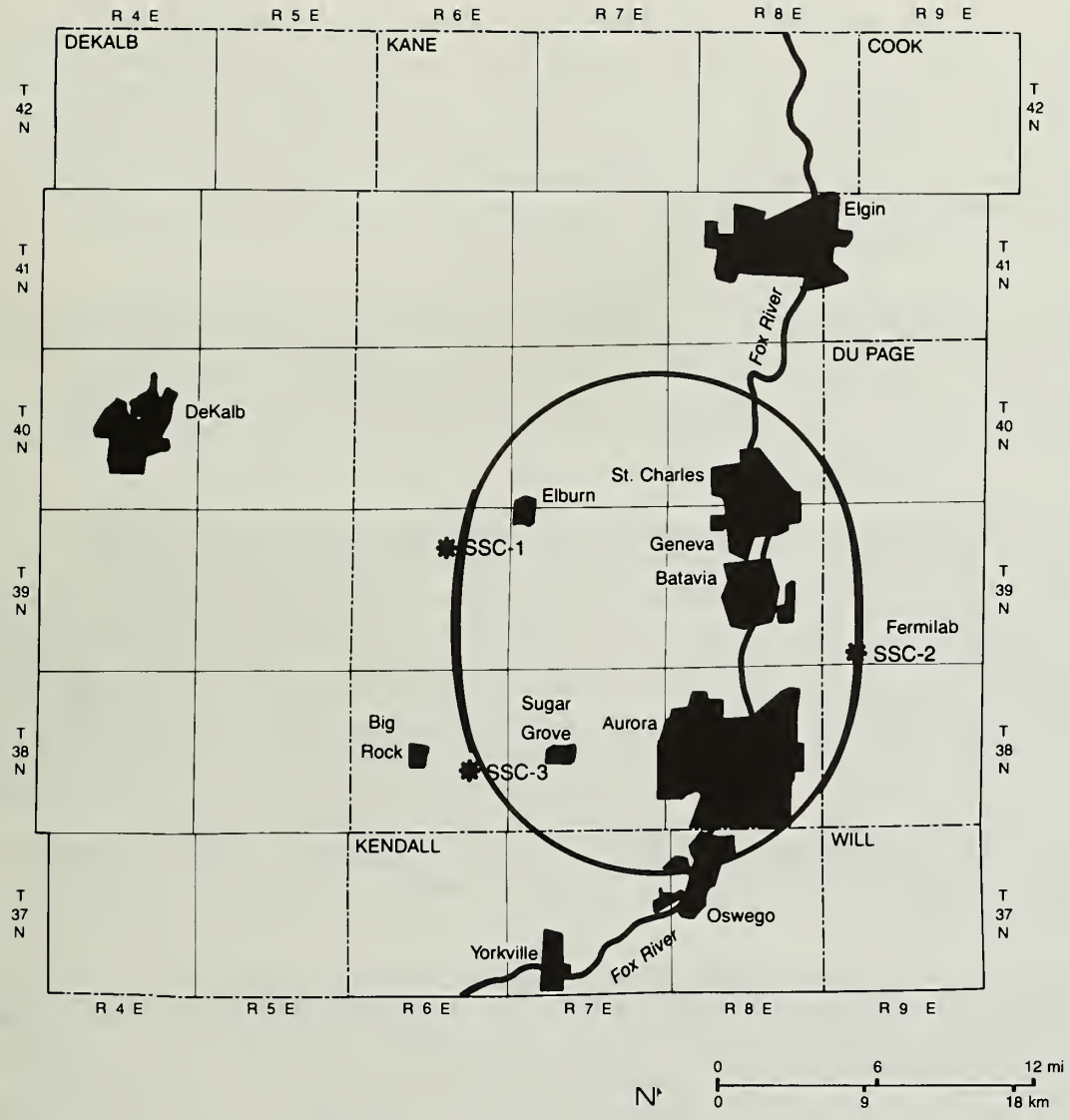

Figure 10 SSC study area showing SSC-1, -2, and -3, three 8-inch boreholes where geologic samples were obtained to be analyzed for natural radioactivity. Stars indicate locations.

The spectral gamma ray geophysical tool, run by Schlumberger Well Logging Company, Inc., uses a detection system consisting of a photomultiplier tube and a sodium iodide scintillation crystal mounted in a Dewar flask for maximum temperature stability. Due to limitations of the detector system and the degradation of gamma energies as they travel from their point of origin to the detector (primarily due to Compton Scattering), the discrete spectrum becomes "smeared" and is referred to as the potassium:uranium:thorium (KUT) spectrum.

The Schlumberger borehole system corrects for this smearing of spectral information by assigning individual spectral windows for potassium-40, uranium-238, and thorium-232. Spectral information is collected for potassium at an energy window centered at 1.46 MeV, for equivalent uranium-238 (via bismuth-210) at 1.76 MeV, and for equivalent thorium-232 (via thallium-208) at 2.62 MeV.

Potassium-40 activities are measured directly. The concentration of total potassium is calculated from the isotopic abundance of potassium-40. However, uranium-238 and thorium-232 do not have clear peaks with their disintegrations. Therefore, activities of these isotopes are determined by measurement of the activities of the daughter isotopes, bismuth-214 and thallium-208. Concentrations of the parent isotope are calculated from an assumption of radioactive equilibrium between parent and daughter nuclides. The terms equivalent uranium and equivalent thorium are used in reference to the concentrations that are not measured directly. [Note that the determination of uranium and thorium concentration with the Schlumberger borehole spectral gamma radiation system (SGR) is similar to the approach used to interpret the NURE airborne data.]

The Schlumberger SGR system operates by placing a detector in a borehole to count disintegration events occurring in the geologic materials. The information gathered as the detector is slowly retrieved from a borehole is transmitted to a digital computer on the surface where processing determines the concentrations of potassium, uranium, and thorium present in the geologic materials. The results are displayed as a continuous record of concentrations related to depth in the borehole.

The spectral gamma ray records for the three boreholes in the SSC siting area are presented in figure 11, which presents the SGR logs for the boreholes in a general west to east perspective and correlates the major stratigraphic units in the bedrock. The correlation is based on study of the complete suite of geophysical records performed on the boreholes and study of rock chips collected during the drilling.

The concentrations of potassium, uranium, and thorium determined by the borehole method were compared with concentrations determined by instrumental neutron activation analysis (INAA) on discrete samples of rock chips collected in the drilling program. The INAA procedures are referenced in Harvey et al. (1983).

The laboratory analytical program initially focused on rock samples from Test Hole SSC-1. Two separate criteria were used to select samples for

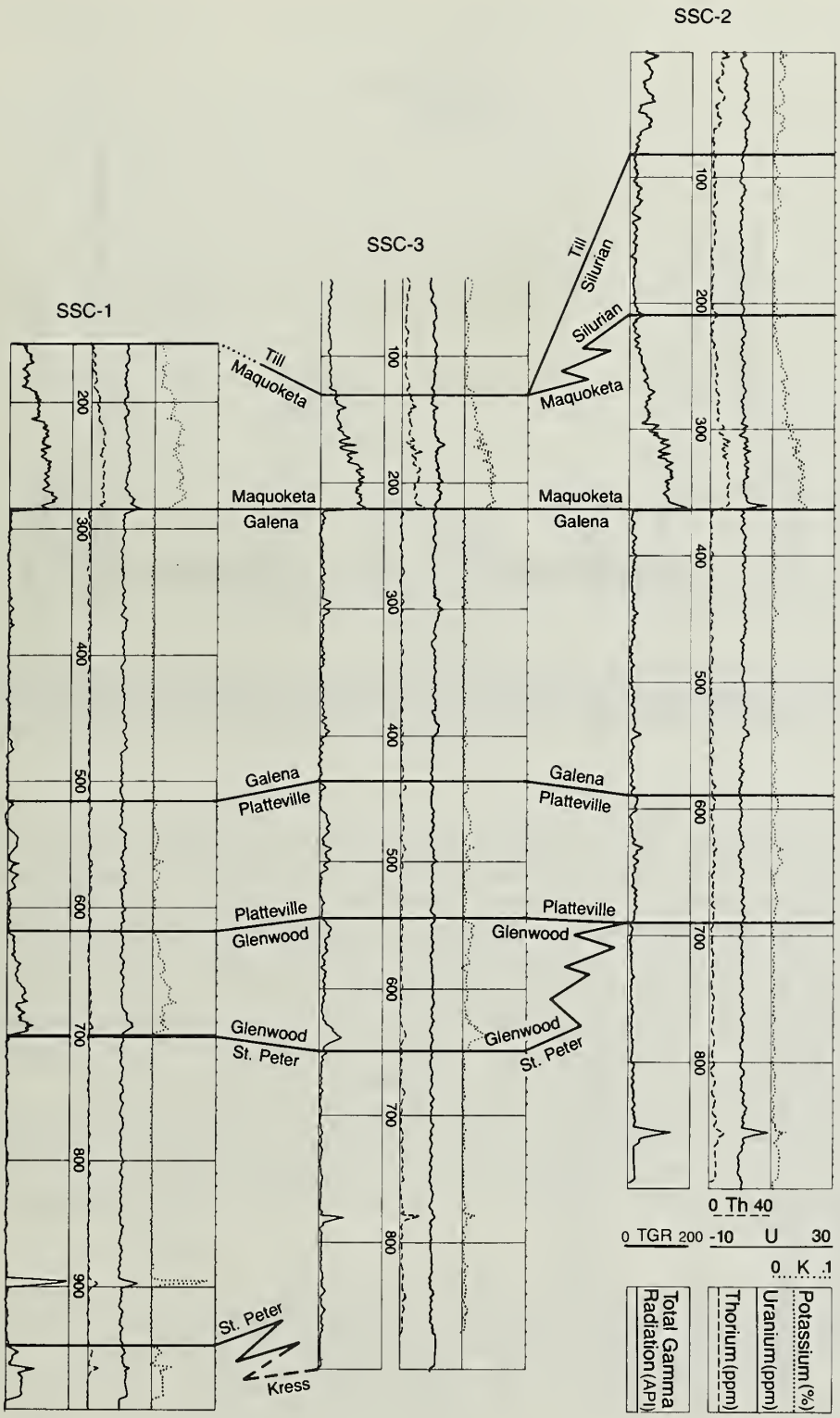

Figure 11 Spectral gamma ray records showing concentrations of total potassium (%), equivalent thorium (ppm) and equivalent uranium (ppm) for in situ measurements in three boreholes in the SSC study area. The location of boreholes is shown in Figure 10.

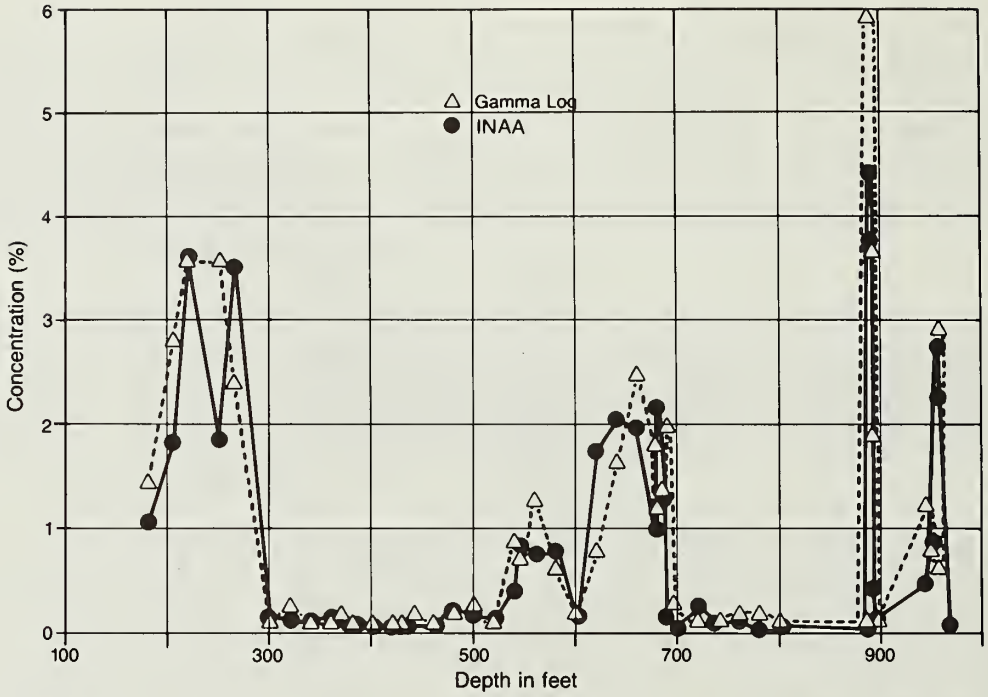

Figure 12 Concentrations of total potassium (%) measured in geologic materials in SSC-1. The plot compares laboratory instrumental neutron activation analyses on rock chips to in situ measurements with a spectral gamma ray sonde.

laboratory analysis. One criterion was to select samples from zones that displayed relatively high radioactivity on the spectral gamma ray log. A second criterion was to ensure an accurate, unbiased comparison of the potassium-uranium-thorium concentration shown on the SGR log with concentrations measured analytically. To satisfy this criteria, rock samples from boring SSC-1 were analyzed on a 20-foot spacing through the depth interval of 300 to 800 feet. The analytical results for boring SSC-1 are shown in figures 12, 13, and 14. The three figures compare the INAA concentrations for potassium, uranium, and thorium with concentrations determined with the SGR method. The good correlation between the INAA and SGR methods has been discussed elsewhere (Gendron et al. 1988). In contrast to the analytical program for boring SSC-1, only a limited number of zones from borings SSC-2 and SSC-3 were sampled for laboratory analysis.

Table 2 shows the mean concentrations of potassium, uranium, and thorium in the major bedrock units penetrated at the three boreholes; these values were determined in the laboratory with the INAA method. Values for potassium, equivalent uranium, and equivalent thorium for the Silurian dolomite were calculated from the SGR record from borehole SSC-2.

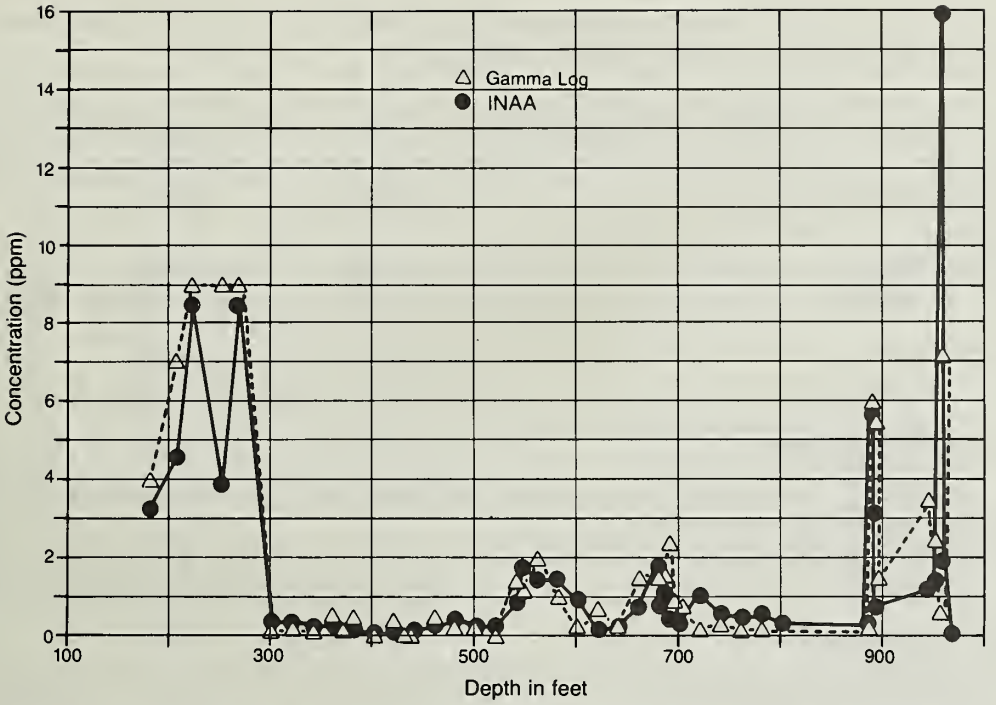

Figure 13 Concentrations of thorium (ppm) measured in geologic materials in SSC-1. The plot compares laboratory instrumental neutron activation analyses on rock chips to in situ measurements with a spectral gamma ray sonde.

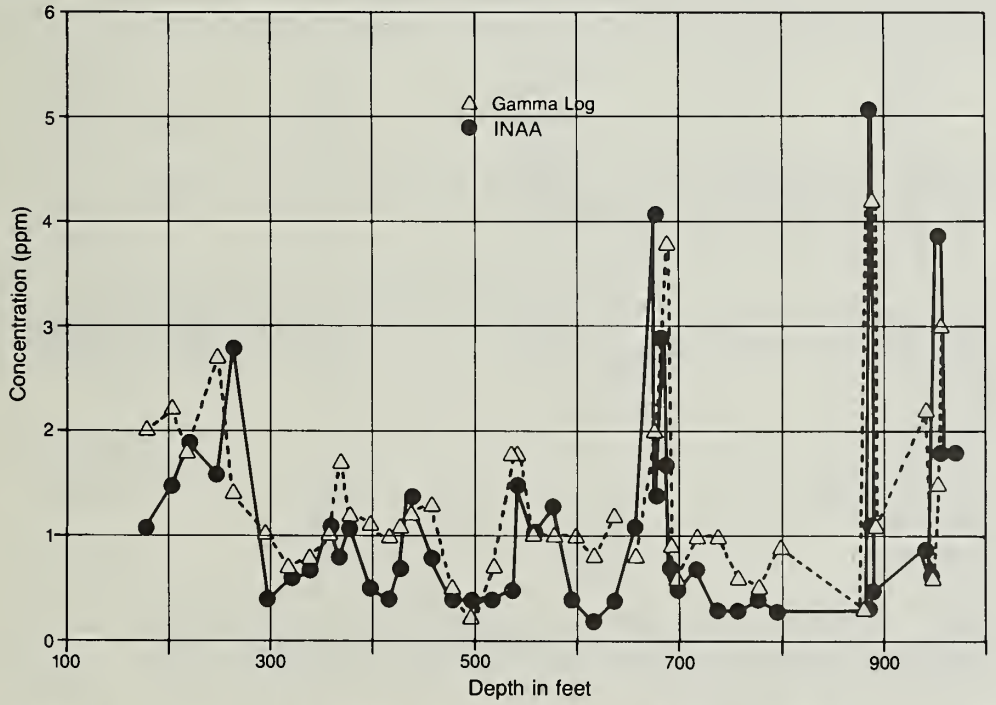

Figure 14 Concentrations of uranium (ppm) measured in geologic materials in SSC-1. The plot compares laboratory instrumental neutron activation analyses on rock chips to in situ measurements with a spectral gamma ray sonde.

Table 2. Mean concentrations of potassium, uranium, and thorium in major bedrock units in the proposed SSC siting area

Bedrock unit	No. of samples	K (%)	U (ppm)	Th (ppm)
Silurian dolomite	*	0.62	0.45	2.55
Maquoketa shale	7	3.02	2.45	7.2
(range)		(0.02-4.74)	(0.30-4.60)	(0.30-11.5)
Galena dolomite	18	0.16	0.78	0.44
(range)		(0.03-0.91)	(0.40-1.40)	(0.10-2.00)
Platteville dolomite	14	0.43	0.79	0.84
(range)		(0.08-0.94)	(0.30-1.50)	(0.30-1.80)
Glenwood sandstone	11	1.11	1.2	0.65
(range)		(0.15-2.16)	(0.20-4.10)	(0.24-1.90)
St. Peter sandstone	17	0.63	1.05	1.41
(range)		(0.01-4.41)	(0.30-5.10)	(0.35-5.80)
Kress sandstone	4	1.47	2.03	4.90
(range)		(0.05-2.74)	(0.60-3.90	(0.10-16.00)

Note: Determined by Instrumental Neutron Activation Analysis.
* Concentrations of potassium, equivalent uranium, and equivalent thorium determined from borehole spectral gamma radiation measurements.

Table 3. Concentrations of major radionuclides in major rock types and soils worldwide

Material	Radioactive element (concentration) K (%)	U (ppm)	Th (ppm)
Shale	2.7	3.7	12
Sandstone			
clean	<1	<1	<2
dirty quartz	2	2-3	3-6
arkose	2-3	1-2	2
Carbonate	0.3	2	2
Soils	1.5	1.8	9

Source: National Council on Radiation Protection and Measurements Report No. 45 (1975).

The high concentrations of radioactive elements occur in the shale lithologies; the highest concentrations are present in the Maquoketa Shale Group. Shaly zones are also present in the Glenwood Formation and the Kress Member of the St. Peter Sandstone. Low concentrations of radioactive elements are present in the dolomites with the lowest concentrations measured in the Galena Group. Clean sandstones in the SSC study area have low concentrations of radioactive elements. The high values shown in the range for the sandstones represent finer grained rocks with a component of clay in the matrix. The finer grained shaly sandstones occur commonly in the Kress and the Glenwood, and very rarely in the St. Peter.

Table 3 presents a summary compilation of the concentrations of potassium, uranium-238, and thorium-232 in major rock types from measurements worldwide (NCRP, 1975). Table 4 presents a summary of radioactive element data for samples collected throughout Illinois. Comparisons of tables 2, 3, and 4 illustrate that average concentrations in the SSC study area are low compared with values determined in other regions of Illinois and worldwide.

Table 4. Summary of uranium, thorium, and potassium data for major rock types in Illinois

Rock type	No. of samples	Radioactive element (concentration) K (%)	U (ppm)	Th (ppm)
Shale				
Blocher	24	2.65	12	6.6
Selmier	79	3.65	10	10
Grassy Creek	185	3.73	26	10
Hannibal	60	4.56	7	12
Anna	8	2.52	31	12.5
Energy	4	2.91	5	15
Various	11			9
Recent sediments				
Lake Michigan	286	1.82	2.3	5.8
Illinois River	112	2.00		13
Carbonates				
Limestones	4	0.31	4.5	2.7
Various	10		1.7	
Sandstone	14		1.5	

Sources: Results are taken from Frost, Zierath and Shimp, 1985; Cahill, 1981; Cahill and Steele 1986; DeMaris et al., 1983; and Gilkeson et al., 1978.

The data gathered on the concentrations of radioactive elements in rocks of the SSC siting area demonstrate that the rocks have low concentrations of radioactive elements, and that rock debris generated during construction of shafts or the tunnel does not pose a radioactivity hazard requiring special handling or disposal.

AIRBORNE RADON CONCENTRATIONS

Radon is a radioactive gas that is produced naturally in geologic materials by the normal decay of isotopes in the uranium-238 (fig. 1) and thorium-232 decay series (fig. 2). The public health impact of radon-222 (half-life 3.82 days) in the uranium-238 decay series is an issue that is now receiving national attention. There is less health concern for radon-220 in the thorium-232 decay series because of its very short half-life (55 s). The health concern that is most significant for any population exposure, occupational or environmental, is the alpha dose deposited in the tracheobronchial region through inhalation of the short-lived radon-222 daughters: polonium-218, lead-214, bismuth-214, and polonium-214.

Exposure to radon-222 is defined in terms of the air concentration of radon daughters in units of the working level (WL). One WL is defined as that concentration of short-lived radon daughters that has a potential alpha energy release of 1.3×10^5 MeV per liter of air. Cumulative exposure is defined in working level months (WLM), which equals exposure in working level times exposure duration in multiples of the 170-hour occupational month. The occupational standard for radon daughter exposure in the United States is currently set at 4 WLM per year.

Secular equilibrium between radon and daughter nuclides is seldom found in ambient atmospheres. The daughter nuclides are chemically active solids that attach to surfaces such as walls, furniture, clothing, and to airborne particles. The nuclides attached to airborne particles deliver the significant dose to the lungs. The equilibrium ratio of the daughter nuclides in indoor air to the radon concentration generally ranges from 0.3 to 0.5. Concentrations of radon in air are commonly expressed as pCi/L. The U.S. EPA has set 4.0 pCi/L as an action level guideline for indoor radon concentrations. For an equilibrium ratio of 0.5, 4.0 pCi/L radon represents 0.02 working levels. Similarly, a radon concentration of 200 pCi/L would represent 1 working level.

The time length of residential occupancy may differ significantly from the standard work-related occupational month, which is 170 hours. Cumulative exposure at a given concentration is more than four times that for occupational exposure (8766 hours versus 2000 hours on an annual basis).

Airborne Concentrations of Radon-222 Outdoors

The average outdoor radon-222 concentration over continents is estimated to be 200 pCi/m^3 or 0.2 pCi/L (NCRP, 1984). A survey of published measurements by Gesell (1983) found that the mean value for outdoor concentrations of radon-222 for normal areas of the contiguous United States lies in the range of 100 to 400 pCi/m^3 and averages about 250 pCi/m^3 or 0.25 pCi/L. Measurements taken in the late spring and summer of

Table 5. Radon-222 concentrations measured in 144 residences

pCi/L	Basement (% occurrence)	First floor (% occurrence)
<1	22	37
1-4	51	49
>4-10	19	13
>10	8	1

Note: Analyses on grab samples collected by Argonne National Laboratory. In each case, basements and first floors represent 124 individual measurements.

Table 6. Radon-222 concentrations in indoor living space in northeastern Illinois counties

County	No. of samples	Geometric mean	Arithmetic mean	Samples in range >4-20 pCi/L	Samples in range >20 pCi/L
Cook	873	1.4	2.13	95	4
De Kalb	11	1.5	1.5	0	0
Du Page	292	2.03	3.05	66	1
Kendall	7	2.6	2.8	1	0
Lake	144	1.4	1.8	13	0
McHenry	31	1.9	2.6	4	0
Kane	52	2.3	3.1	14	0
	1,410	weighted mean	2.3	193	5
U.S.	34,280	1.7	3.6	5,813	775

Note: Analysis by charcoal canister method by Dr. Bernard Cohen, University of Pittsburgh, Pennsylvania.

1960 at Argonne National Laboratory found an average radon-222 concentration of 300 pCi/m^3 and 260 pCi/m^3 at heights of 1 and 4 m above ground surface, respectively (Pearson, 1967). A calculation applying the National Council on Radiation Protection (NCRP) model for predicting lung cancer deaths from continuous environmental exposure to radon (NCRP, 1984) results in a lifetime risk of 0.06 percent for an average outdoor radon concentration of 300 pCi/m^3.

Airborne Concentrations of Radon-222 Indoors

There is currently a great national concern about the concentrations of radon-222 present in indoor environments. Geologic materials immediately surrounding the substructure of a building are the principal sources of indoor radon. For homes with private wells, radon released through water use may also supply a significant fraction of the total radon in the indoor environment. (Radon concentrations in groundwater are discussed in a separate subsection of this report.)

National, state, and local authorities have initiated several programs to measure and evaluate regional indoor radon concentrations.

The first measurements of indoor radon in homes in northeastern Illinois are from a study of 144 single family homes located in the vicinity of Argonne National Laboratory. Dr. Richard Toohey (personal communication, 1986) of Argonne National Laboratory provided the values shown in table 5. Analysis was based on grab samples collected during brief visits to the homes. The samples may not be representative of the long-term average concentrations present in the indoor atmosphere.

Twenty-seven percent of the measurements in basements were greater than the U.S. EPA guideline of 4.0 pCi/L; the maximum concentration measured in a basement was 50 pCi/L. Fourteen percent of the first floor readings exceeded 4.0 pCi/L; 36 pCi/L was the maximum concentration measured.

The homes measured in the Argonne National Laboratory Survey are located east and southeast of the SSC study area. Home construction and physical settings (associations of landscapes and geologic materials) are comparable to conditions in the proposed siting area.

A national survey of indoor radon concentrations now underway is being coordinated by Dr. Bernard Cohen at the University of Pittsburgh in Pennsylvania. Measurements are taken in indoor living space with activated charcoal radon monitors. The results for eight counties in northeastern Illinois (including the SSC study area) are presented in table 6. An unfortunate problem with this data set is that the county tabulation did not discriminate between Kankakee and Kane County.

The Cohen data set includes 1,410 measurements of radon in residences in the eight counties of northeastern Illinois compared with 34,280 measurements for the total national survey. The arithmetic mean value for the eight-county region of 2.3 pCi/L is lower than the national value of 3.64 pCi/L. Also, only 0.35 percent of the measurements in living spaces in the eight-county region exceeded 20 pCi/L (compared with 2.26 percent of living spaces exceeding 20 pCi/L in the total national survey.)

The samplings in the nationwide study may not be random in a truly statistical sense. Greater sampling frequency in areas of known or suspected high radon concentrations may bias the averages high and give a disproportionate weight to higher ranges in radon concentrations. The data in table 6 and the comparisons should be viewed with this in mind.

The Illinois Department of Nuclear Safety has initiated a program to evaluate indoor radon concentrations throughout the state of Illinois. The preliminary results of the eight counties in northeastern Illinois (including the SSC study area) are presented in table 7.

The Illinois Department of Nuclear Safety data set includes 738 measurements in indoor living spaces in eight counties of northeastern Illinois. The measurements were made with track etch detectors that were exposed in the houses for one to three months during the 1987 winter heating season. Although these data represent a longer measurement time period, they are conservatively high due to low ventilation during the heating season. Only six homes exceeded 20 pCi/L in the basement and no homes exceeded this level on the first floor. The number of homes in the

Table 7. Radon-222 concentrations in indoor living space in northeastern Illinois counties during the 1987 winter heating season

Basement

County	Number of measurements					% occurrences above	
	Total	<4.0	4.0-7.9	8.0-19.9	>20.0	4 pCi/L	20 pCi/L
Boone	52	20	25	7	0	61.5	0.0
Cook	208	168	31	9	0	19.2	0.0
De Kalb	50	26	20	4	0	48.0	0.0
Du Page	134	86	32	13	3	35.8	2.2
Kane	59	27	18	12	2	54.2	3.4
Kendall	26	9	11	6	0	65.4	0.0
Lake	79	67	9	3	0	15.2	0.0
McHenry	69	46	16	6	1	33.3	1.4
Regional	677	449	162	60	6	33.7	0.9

First Floor

County	Number of measurements					% occurrences above	
	Total	<4.0	4.0-7.9	8.0-19.9	>20.0	4 pCi/L	20 pCi/L
Boone	1	1	0	0	0	0.0	0.0
Cook	49	42	7	0	0	14.3	0.0
De Kalb	6	5	1	0	0	16.7	0.0
Du Page	31	27	4	0	0	12.9	0.0
Kane	12	9	3	0	0	25.0	0.0
Kendall	2	2	0	0	0	0.0	0.0
Lake	10	9	0	1	0	10.0	0.0
McHenry	8	8	0	0	0	0.0	0.0
Regional	119	103	15	1	0	13.4	0.0

Note: Analysis by track etch detectors placed by the Illinois Department of Nuclear Safety for a minimum of one month.

4 to 20 pCi/L range was 13.4 percent for first floor which compares with the 13.7 percent found by the University of Pittsburgh data set. The results for basements indicate 33.7 percent of the homes in the 4 to 20 pCi/L range. Results in the range of 4 pCi/l to about 20 pCi/L are considered above average for residential structures. At these levels, the U.S. EPA recommends that a follow-up measurement be made. If the results are confirmed, the U.S. EPA recommends that action be taken to lower the levels to near 4 pCi/L within a few years.

Airborne Concentrations of Radon-222 in Underground Shafts and Tunnels

Information is required on the concentrations of radon-222 that will be present in the work environment during excavation of shafts and tunnels for the SSC and during its operation. The information is necessary for sizing the required ventilation systems.

Table 8. Radon-222 concentrations in soil gas and atmosphere at at U.S. Geological Survey research area near Sheffield, Illinois

Stratigraphic unit	Measurement in soil gas (pCi/L)
Peoria Loess	1000-2000
Roxanna Silt	1000-1500
Radnor Till	1000-3000
Toulon Sand	190-290
	Measurements in atmosphere
Underground research tunnel	50-200
0.5 ft above land surface	1-3

The U.S. Geological Survey has measured radon-222 in soil gas samples collected from in situ unconsolidated geologic materials near the town of Sheffield in Bureau County, Illinois. The measurements were taken in the vicinity of a low-level radioactive waste disposal site, but they represent natural background concentrations (Rob Striegl, 1985, USGS, personal communication). The radon concentrations shown in table 8 are from measurements taken from August 1984 to August 1985 (Rob Striegl, 1985, USGS, personal communication).

The underground research tunnel is constructed in the Radnor Till. The radon-222 concentrations measured in the poorly ventilated tunnel are of a level for concern, but they are much lower than the values measured in soil gas in the Radnor Till. The difference in values is possibly due to slow transport of radon from the fine-grained materials. Radon at the level of the concentrations measured in the tunnel could easily be controlled by ventilation.

Data on radon-222 concentrations in underground workings other than uranium mines are limited. Measurements in coal mines resulted in low values, principally because the use of ventilation in operating coal mines to control other problems, such as methane, is also very effective in controlling radon-222. A study by Rock et al. (1975) of 223 coal mines (1,581 samples) found only two mines to have radioactive aerosol concentrations greater than 0.2 WL. Significantly, no measurements indicated concentrations in excess of 0.3 WL. Ventilation is also believed to be the reason for very low radon-222 values measured in the New York subway system (Robert T. Beckman, 1986, personal communication, U.S. Department of Labor).

Results from monitoring Newfoundland fluoride mines (Dory and Corkill, 1985) determined that geologic environments other than uranium resources may supply high radon concentrations to mine environments. Radon daughter monitoring determined values above 100 WL in poorly ventilated wet stopes in the fluoride mines. Values measured in wet stopes were significantly higher than those measured in dry environments. Groundwater is a source of radon in the wet environments. The wet environments are due to fractured and fissured rock that is open to groundwater flow. Radium in encrustations on the fractured and fissured rock is a significant source

of radon in groundwater. The observation that wet underground environments have higher radon concentrations is also supported by measurements in caverns. For example, the highest concentrations for Mammoth Cave in Kentucky (21 WL) are in poorly ventilated wet passageways in the region of groundwater infiltration (Bob Carson, 1986, personal communication, Mammoth Cave, Kentucky). Values in poorly ventilated, dry passageways are much lower, but they still often exceed 1 WL. Also of interest are concentrations measured in a poorly ventilated area at the base of a 256-foot shaft excavated for an elevator at Mammoth Cave. Concentrations are generally 1.1 to 1.2 WL with maximum values of 1.8 WL measured occasionally.

In the SSC study area, the tunnel and research chambers would be constructed in the Galena and Platteville Dolomite Groups. The principal rock unit for the tunnel is the Galena. Along the western side, construction of the tunnel and research chambers would also include the upper part of the Platteville. Table 2 presents analyses of radioactive elements in dolomites from the Galena and Platteville Groups in the proposed study area. Carbonates have low concentrations of radioactive elements. Furthermore, the concentrations in the Galena-Platteville dolomites in the SSC study area are low compared with the mean concentration measured in carbonate rocks worldwide (table 3).

The most significant source of radon in the tunnel atmosphere will be emanation of radon from the rock walls. An additional minor source of radon will be from inflows of groundwater during the boring of the tunnel and research chambers. Groundwater sources of radon will be insignificant after the grouting program to seal fractures and crevices.

A sampling program was conducted to evaluate the radon groundwater concentration in the Galena-Platteville dolomites in the SSC study area. This program also included the collection of groundwater samples from wells finished in the glacial drift and the Silurian dolomite. The analytical results are presented in table 9. The location of wells is presented in figure 15. Dissolved radon-222 concentrations in groundwater from wells open to the Galena-Platteville dolomite vary from 129 to 740 pCi/L. The mean concentration for measurements from 19 wells is 295 pCi/L. The low values for dissolved concentrations of radon-222 indicate that the small quantities of groundwater expected to infiltrate the tunnel will be an insignificant source for radon in tunnel atmospheres.

The available data indicate that natural radon concentrations within shafts and tunnels cut into the geologic materials in the SSC study area may exceed occupational levels, but that ventilation will readily reduce the concentrations to acceptable values. The ventilation necessary for other parameters should be adequate to eliminate concern for radon. The low concentrations of uranium and thorium in the dolomites and the low concentrations of radon in groundwater from these rocks are indicators that high radon concentrations will not pose a problem to construction or operation of the SSC.

Table 9. Concentrations of radon-222 and uranium-238 plus uranium-234 in groundwater from the glacial drift, dolomite bedrock, and St. Peter Sandstone in the SSC study area

Well* no.	Location (Sec.-T-R)	Units in open borehole **	^{222}Rn (pCi/L)	^{238}U (ppb)	Activity ratio $^{234}U/^{238}U$	$+^{234}U$ $+^{238}U$ (pCi/L)
GG	15-40N-8E	D	670	1.12	1.16	0.8
DD	14-42N-8E	D	641			
HH	28-40N-8E	D	462			
EE	21-38N-7E	D	499	3.15	1.06	1.1
BB	19-39N-9E	S	740	0.258	2.03	0.2
AA	32-39N-9E	S	706			
A	17-38N-9E	S/M	277	<0.008		<0.1
Z	26-39N-6E	S/M/G	277			
B	2-37N-8E	S/M/G	315	0.104	3.09	0.1
W	16-40N-7E	M/G/P	190			
I	33-40N-8E	M/G/P	277	<0.002		<0.1
E	16-38N-6E	M/G	286	<0.003		<0.1
L	21-40N-7E	G/P	183			
U	17-37N-8E	M/G	448			
+C	24-37N-7E	M/G/P/ST.P	162			
C	24-37N-7E	M/G	172			
G	6-39N-7E	G/P	247	0.347	11.26	1.4
K	10-40N-8E	M/G/P	380			
X	22-37N-7E	G/P	458			
D	16-37N-7E	G	459			
J	6-40N-7E	G/P	223			
S	16-40N-8E	G	324	<0.02		<0.1
N	2-37N-8E	G/P	346			
L	7-40N-8E	G/P	129	0.25	4.57	0.4
Y	18-37N-8E	G	227			
F	3-39N-6E	G/P/ST.P	510			
SSC1-400		G		0.146	2.02	0.1
SSC1-460		G		0.477	2.56	0.56
SSC1-540		P		0.859	5.64	1.9
SSC1-800		ST.P		2.86	6.64	7.21

* The location of wells is shown on figure 15.

** D - drift, sand and gravel; S - Silurian; M - Maquoketa; G - Galena; P - Platteville; ST.P - St. Peter.

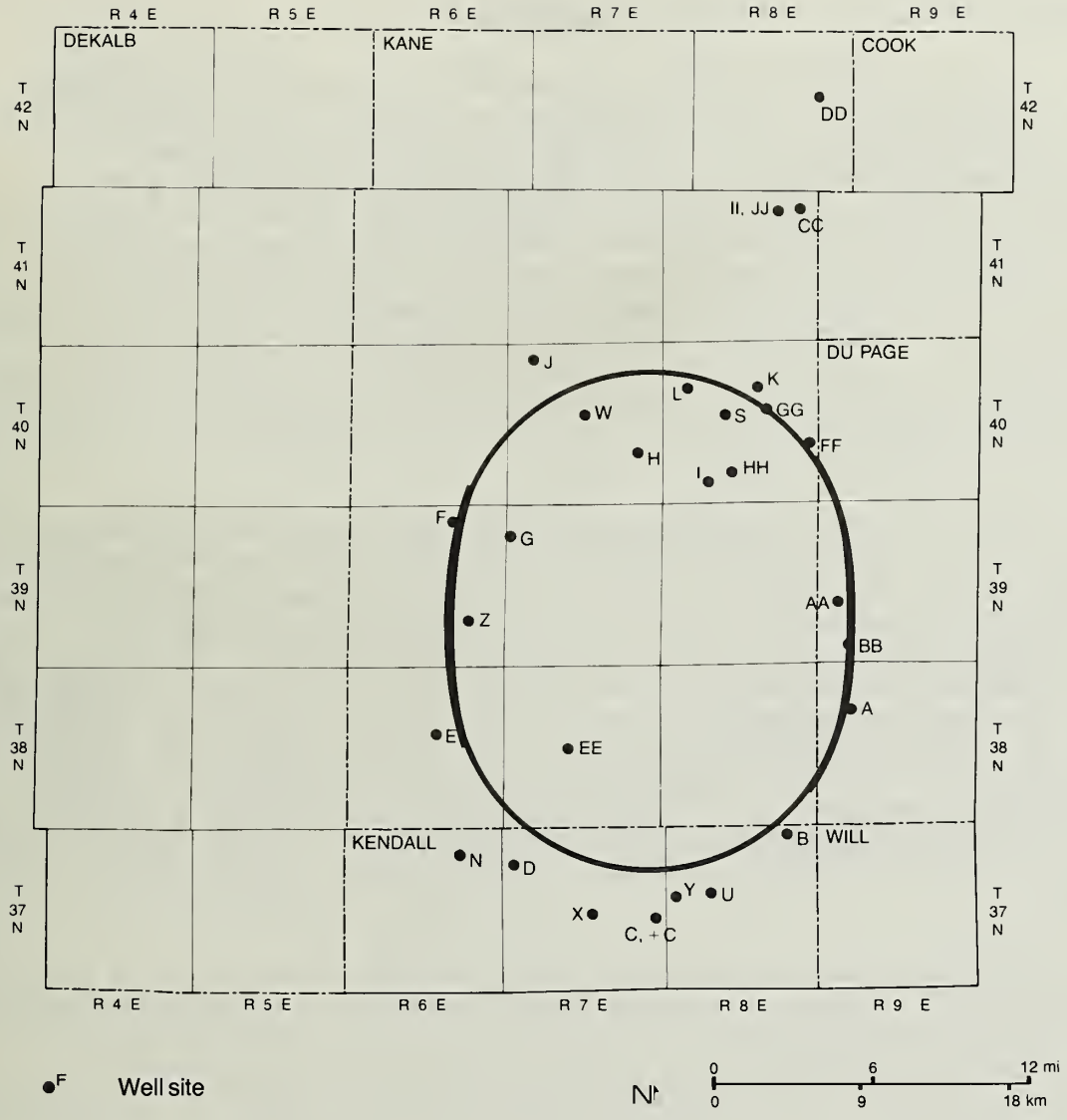

Figure 15 SSC study area showing where groundwater samples were collected for analyses of natural radioactive elements. Analytical results are presented in table 9.

NATURAL RADIOACTIVE ELEMENTS IN GROUNDWATER

Several aquifers are used for groundwater resources in the SSC study area. Stratigraphic columns of geologic materials in the glacial drift and bedrock are presented in figures 16 and 17. The three most significant aquifers are 1) sand and gravel deposits in the glacial drift, 2) fractures and crevices in the shallow Silurian or Maquoketa dolomite bedrock (hydraulic connection often occurs between glacial drift and shallow bedrock), and 3) deep sandstones (St. Peter and Ironton-Galesville) in the Cambrian and Ordovician bedrock. Dolomites confined within the Maquoketa Shale Group and the Galena-Platteville Group occasionally provide limited groundwater supplies to a relatively small number of wells. Wells are often finished in the confined dolomites in localities where the sand and gravel or shallow bedrock do not provide an adequate domestic groundwater supply.

The naturally occurring radioactive elements in groundwater that are of public health concern are members of the uranium-238 and thorium-232 decay series. Two radium isotopes, radium-226 (uranium-238 series) and radium-228 (thorium-232 series) are of primary concern. The U.S. Environmental Protection Agency drinking water standard is 5.0 pCi/L for the combined concentration of the two nuclides. The other isotopes of concern are uranium-238, uranium-234, and radon-222. Methods of analysis for all dissolved radionuclides discussed in this report are cited in Gilkeson et al., 1983. The U.S. EPA expects to promulgate a uranium standard for drinking water soon. The agency has issued a health advisory for uranium of 10 pCi/L, based on considerations of radio-toxicity and chemical toxicity (Richard Cothern, 1986, personal communication, U.S. EPA).

A U.S. EPA drinking water standard for radon-222 does not exist now. Hess et al. (1979) proposed a maximum contaminant level of 10,000 pCi/L for radon-222 in household water supplies based on a concern for radon released from groundwater to indoor air. A recent analysis by Nero et al. (1985) estimates that a groundwater supply with a radon-222 concentration of 10,000 pCi/L will increase the indoor air concentration of radon-222 by 0.65 pCi/L.

Aquifers in the Glacial Drift and Shallow Bedrock

Very limited information exists on the concentrations of specific radioactive nuclides present in groundwater from these aquifers. Table 9 presents analyses for radon-222 and uranium isotopes for groundwater samples collected from four wells in the SSC study area that produce from the glacial drift and for three wells that are open to the shallow bedrock (Silurian and/or Maquoketa). Radon-222 concentrations are low and vary from 277 to 740 pCi/L. Dissolved uranium concentrations are also low and vary from 0.2 to 1.1 pCi/L for the combined concentration of uranium-238 plus uranium-234.

Uranium analyses were performed on groundwater samples collected from two public supply wells finished in the Silurian dolomite at locations east of the SSC study area in Cook and Du Page Counties. The measured

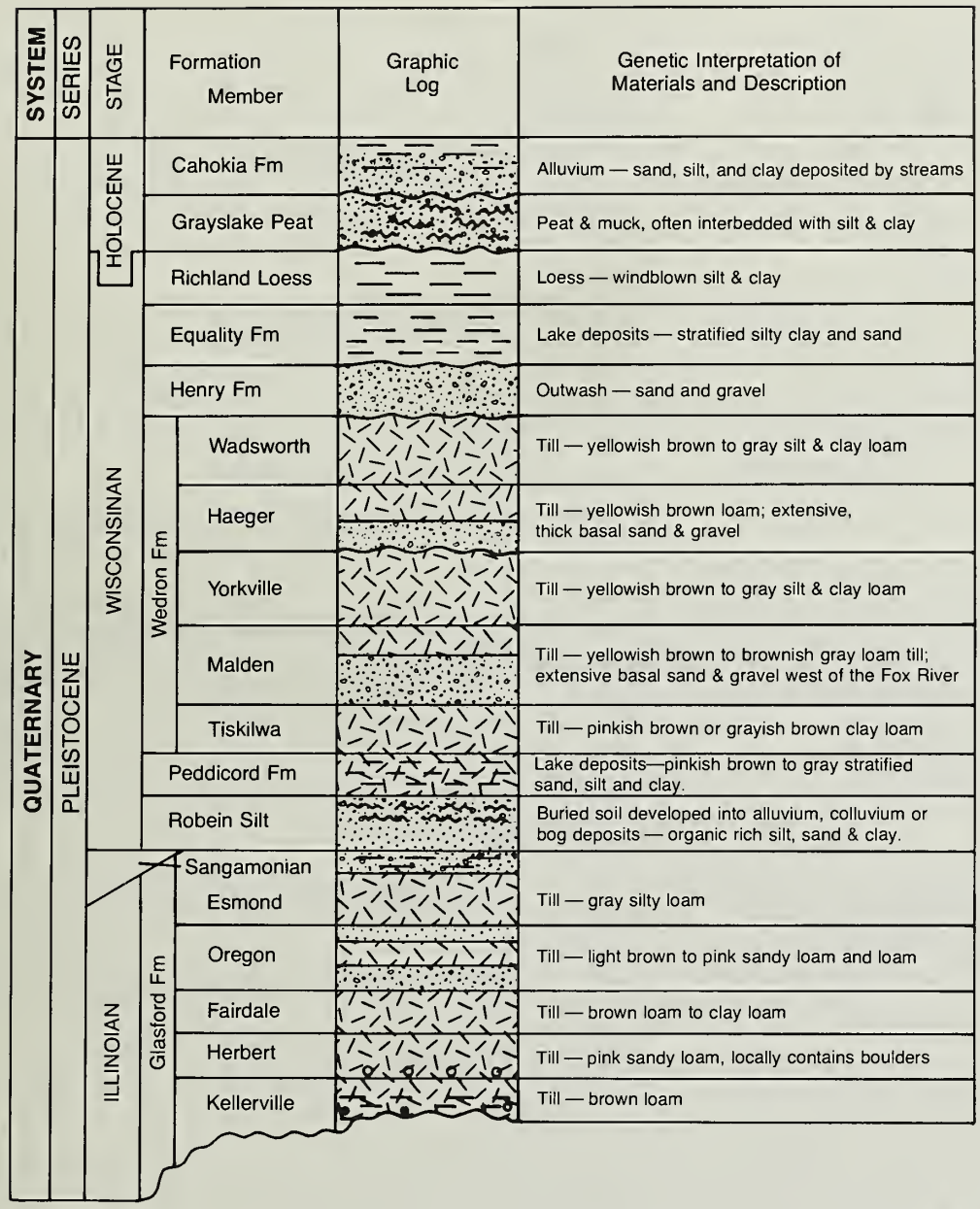

Figure 16 Stratigraphic column of drift deposits in northern Illinois (from Kempton et al., 1985).

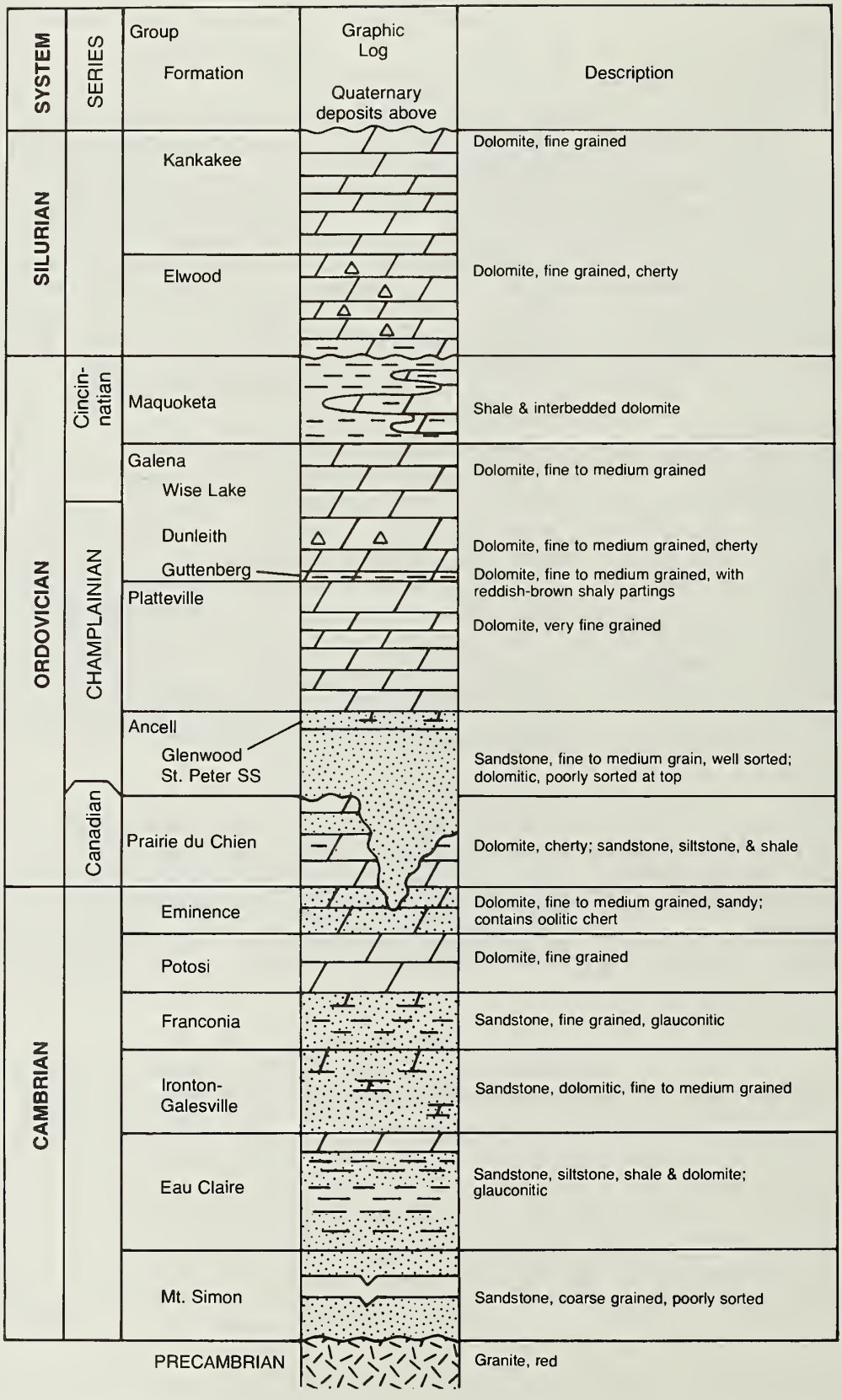

Figure 17 Stratigraphic column of bedrock units in the SSC study area (from Kempton et al., 1985).

concentrations for uranium-238 plus uranium-234 were 0.14 pCi/L for Well no. 2 at Mt. Prospect (Cook County) and 0.28 pCi/L for Well no. 7 at Elmhurst (Du Page County). A radon-222 concentration of 269 pCi/L was measured in groundwater from Well no. 7 at Elmhurst. Radium analyses were performed on groundwater samples collected from an Aurora test well that was constructed to produce groundwater from sand and gravel deposits in the glacial drift. The analytical results were 0.0 ± 0.2 pCi/L for radium-226 and 0.2 ± 0.2 pCi/L for radium-228.

Although data on specific nuclides are very limited, a significant database exists on measurement of gross alpha and gross beta radioactivity in groundwater from public supply wells in the SSC study area. The analytical data are presented in appendix B. The low values are evidence that radium and uranium concentrations are low and in compliance with drinking water standards.

Confined Aquifers in the Maquoketa Shale Group and Galena-Platteville Dolomite

Table 9 presents analyses for radon-222 and/or uranium-234 plus uranium-238 for groundwater samples collected from wells that are open to the confined portions of the Maquoketa Shale Group and/or the Galena-Platteville Dolomite Group. Radon-222 concentrations in groundwater from these rock units are low (ranging from 128 to 439 pCi/L). The concentration of uranium-234 plus uranium-238 is also low, ranging from <0.1 to 1.9 pCi/L, for analyses on groundwater samples collected from six wells and from three depths in the borehole of SSC-1.

Actual measurements of specific nuclides in groundwater from the Maquoketa Shale Group are very limited for northeastern Illinois. Concentrations measured at one well producing groundwater from the Maquoketa at a location northwest of Elgin were 0.2 pCi/L for radium-226, 0.003 pCi/L for uranium-234 plus uranium-238, and 201 pCi/L for radon-222.

The available measurements of gross alpha and beta activities for groundwater from confined portions of aquifers in the Maquoketa Shale Group across northeastern Illinois (appendix B) indicate that radium and uranium concentrations are very low. Representative examples are the Bangs-Union Parker well, the two wells at Lake Marian in the Woods, and the Wermes Well No. 2 listed under Kane County in Appendix B. A groundwater sample from the Bangs-Union Parker well was analyzed for radium concentrations. The results were 0.53 pCi/L for radium-226 and 0.62 pCi/L for radium-228.

Groundwater from Sandstone Aquifers in the Cambrian-Ordovician Bedrock

Extensive research has been conducted on the distribution of radioactive isotopes in groundwater from the deep sandstones in northeastern Illinois (Gilkeson et al., 1983, 1984). The research focused on identifying geochemical mechanisms responsible for the occurrence of high concentrations of radium-226 and radium-228 in groundwater produced from public water supply wells finished in the Cambrian and Ordovician bedrock. The research found that the high radium concentrations were in groundwater produced from the sandstones, with the highest concentrations present in groundwater from the Ironton-Galesville, the major aquifer.

Figures 18 through 22 present the regional distribution of radium-226, radium-228, uranium-234 plus uranium-238, and radon-222 in groundwater from the Cambrian-Ordovician, with the Ironton-Galesville as the significant source of groundwater for most supply wells.

Figures 18 and 19 present the regional distribution of radium-226 and radium-228, respectively. Radium-226 concentrations vary from 0.5 to greater than 15 pCi/L; concentrations increase from west to east across the region, with the lowest values measured in the southwest where the Maquoketa Shale Group is eroded. Figure 19 shows a few supply wells that also receive groundwater from the Mt. Simon sandstone. An interesting feature is that groundwater from wells that reach only the upper section of the Mt. Simon have somewhat lower radium-226 concentrations than nearby wells that are not drilled deeper than the Galesville. Wells that are finished deep in the Mt. Simon, however, produce brackish groundwater with significantly higher radium-226 concentrations. Figure 18 shows a good example of this relationship by a cluster of wells in T38N, R8E where a concentration of 17.5 pCi/L is reported.

There are fewer measurements of radium-228 than of radium-226 concentrations in groundwater. The regional trend is an increase in concentration from west to east, with radium-228 values of less than 2.5 pCi/L in the western part of De Kalb County. Values are generally 5.0 pCi/L and greater within and east of the Fox River valley. Similarly to radium-226, radium-228 concentrations are somewhat lower in wells that produce more groundwater from the carbonate sections or are deepened to produce from the upper part of the Mt. Simon. Brackish groundwater from the Mt. Simon has exceptionally high radium-228 concentrations, which is illustrated in figure 19 by the cluster of wells in T38N, R8E where a concentration of 32.7 pCi.L is reported.

Figure 20 is a map of northern Illinois that presents the regional distribution of radium-228 plus radium-226 in potable groundwater from the Cambrian-Ordovician bedrock. This map predicts that the combined concentration of the two nuclides in the SSC study area ranges from 5 to greater than 15 pCi/L.

The regional variation of uranium-234 plus uranium-238 concentrations in groundwater from the Cambrian-Ordovician bedrock is shown in figure 21. Combined concentrations range from 0.02 pCi/L to 2.5 pCi/L and are less than 0.5 pCi/L throughout most of the region. Values less than 0.1 pCi/L reflect the low solubility of uranium in reducing environments. Concentrations greater than 1.5 pCi/L occur in the southeastern part of the region and reflect an anomalous enrichment of uranium-234 in groundwater. The analyses indicate that the combined concentration of uranium-234 plus uranium-238 in potable groundwater from the Cambrian-Ordovician bedrock is much lower than the U.S. EPA health advisory of 10 pCi/L.

Radon-222 concentrations in groundwater from supply wells open to the Cambrian-Ordovician bedrock are presented in figure 22. Values range from 44 to 385 pCi/L, with concentrations less than 200 pCi/L over most of the region. The values are very low with regard to the proposed drinking water standard of 10,000 pCi/L.

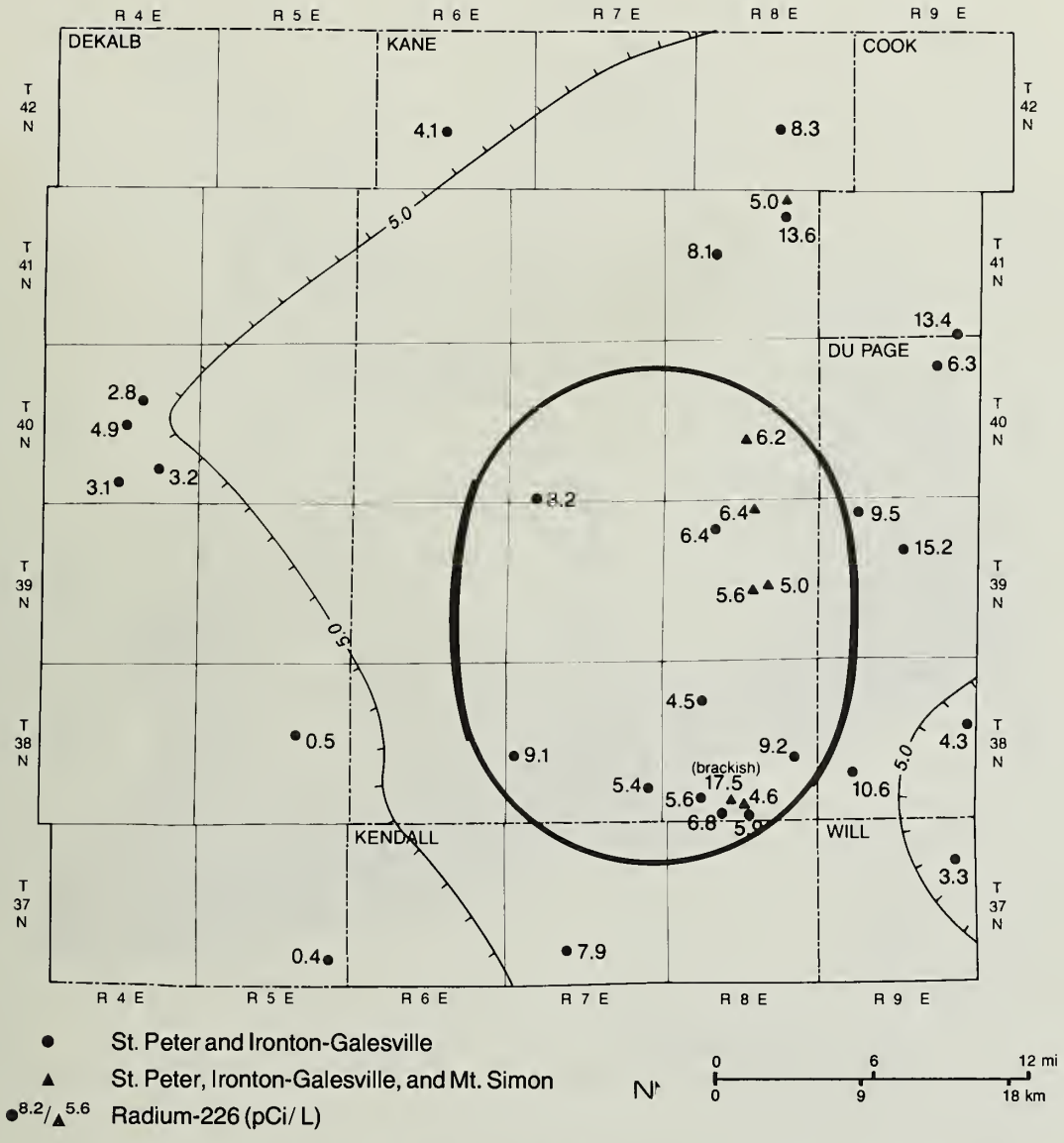

Figure 18 SSC study area showing variation of dissolved concentration of radium-226 in groundwater from the Cambrian-Ordovician bedrock. Principal aquifer is the Ironton-Galesville Sandstone.

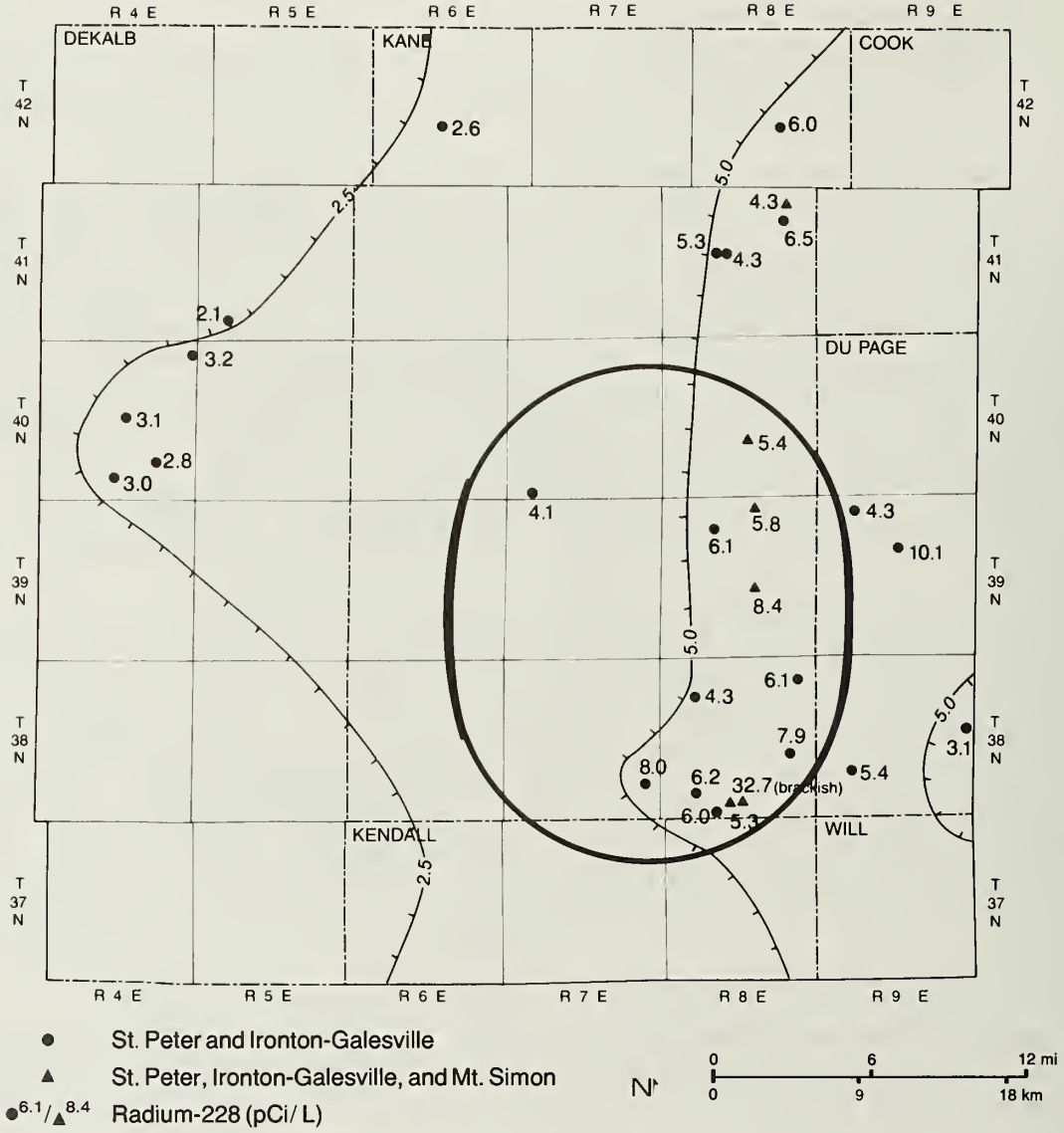

Figure 19 SSC study area showing the dissolved concentration of radium-228 in groundwater from the Cambrian-Ordovician bedrock. Principal aquifer is the Ironton-Galesville Sandstone.

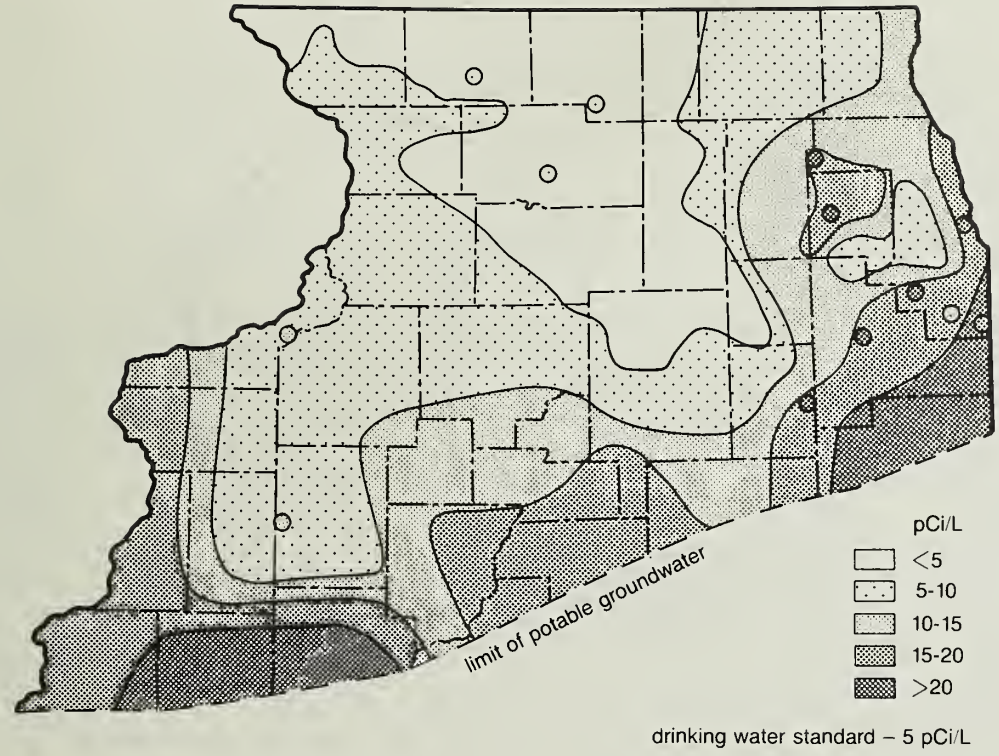

Figure 20 Map of northern Illinois showing the variation of dissolved concentration of radium-226 plus radium-228 in groundwater from the Cambrian-Ordovician bedrock. Principal aquifer is the Ironton-Galesville Sandstone.

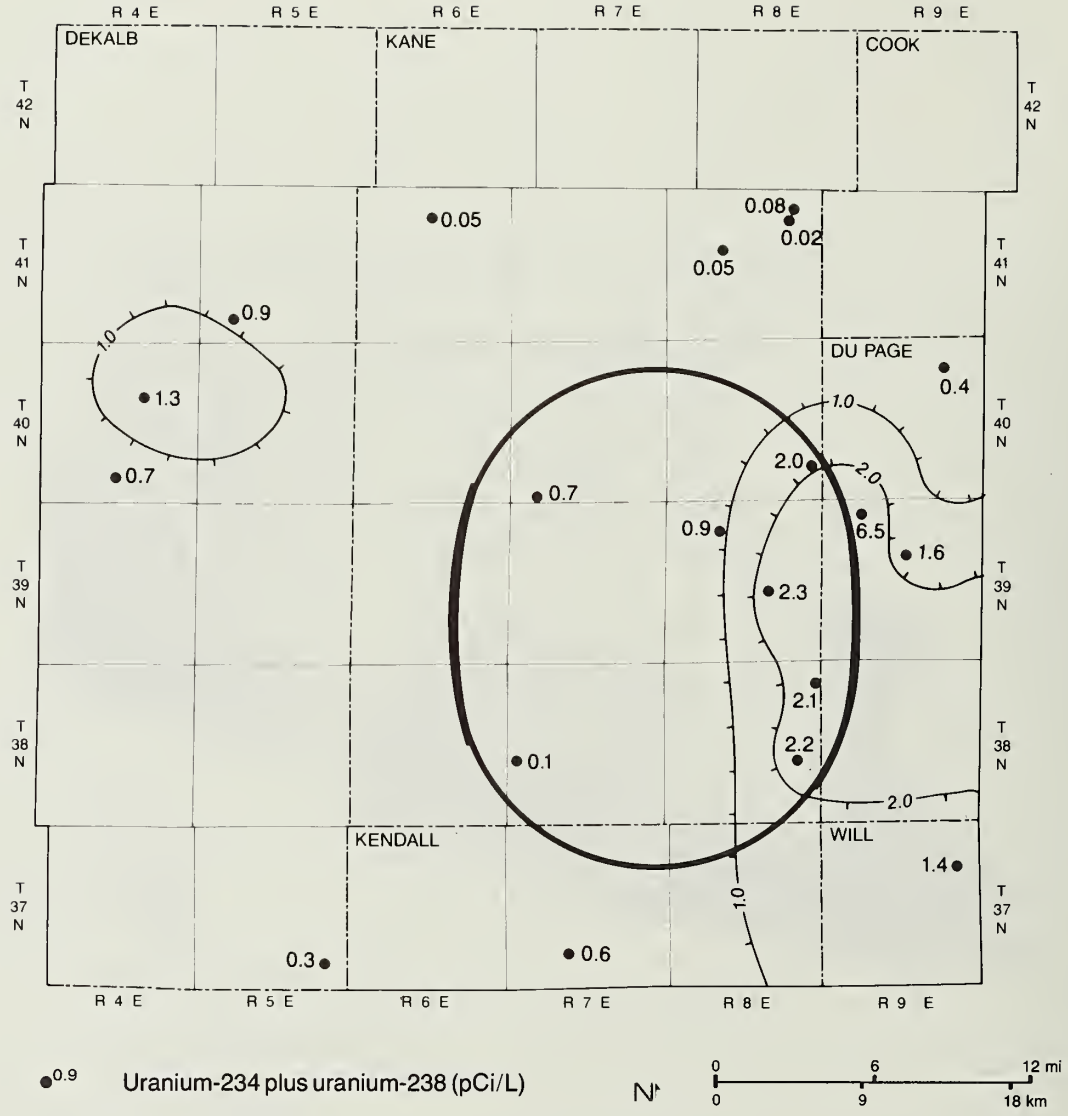

Figure 21 SSC study area showing the variation of dissolved concentration of uranium-234 plus uranium-238 in groundwater from the Cambrian-Ordovician bedrock. Principal aquifer is the Ironton-Galesville Sandstone.

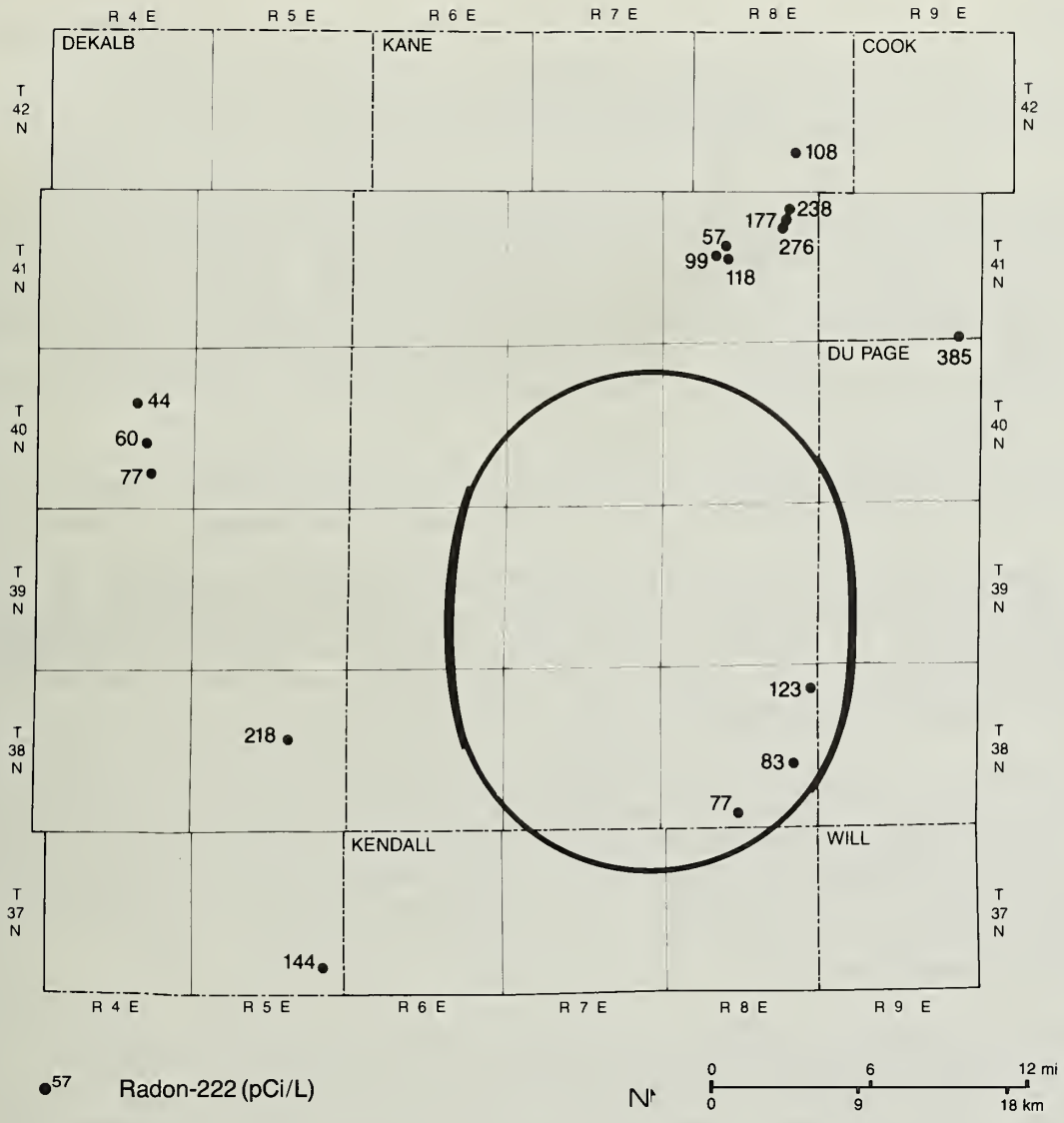

Figure 22 SSC study area showing the variation of dissolved concentration of radon-222 in groundwater from the Cambrian-Ordovician bedrock. Principal aquifer is the Ironton-Galesville Sandstone.

SUMMARY

A large regional and national database has been gathered that is pertinent to natural background radioactivity in the region of northeastern Illinois proposed for siting the SSC.

Within the SSC study area, the concentrations of the three radioactive elements, potassium, thorium, and uranium are relatively low in surficial material. They are comparable to values that occur throughout the Aurora Quadrangle, and to concentrations measured by NURE surveys flown over the Rockford Quadrangle to the north and the Chicago Quadrangle to the east. For example, the average concentrations determined for the Chicago Quadrangle are 1.0 percent for potassium, 3.6 ppm for equivalent thorium, and 1.5 ppm for equivalent uranium (DOE, 1981b). The average concentrations for radioactive elements in surface materials in northeastern Illinois are relatively low when compared with average values measured in surficial materials (soils) worldwide.

The data gathered on the concentrations of radioactive elements in subsurface rocks of the SSC siting area indicate that the rocks have low concentrations of radioactive elements, and that rock debris generated during construction of shafts or the tunnel does not pose a radioactivity hazard that requires special handling or disposal.

Measurements of radon in the indoor living space of 1,410 residences in eight counties of northeastern Illinois had an arithmetic mean value of 2.3 pCi/L. This is lower than the national value of 3.64 pCi/L, which is based on 34,280 measurements. Also, less than 1 percent of the measurements in living spaces in the eight-county-region exceeded 20 pCi/L (compared with 2.26% of living spaces exceeding 20 pCi/L in the total national survey.)

Limited information exists on the concentrations of specific radioactive nuclides present in groundwater from the glacial drift and shallow bedrock aquifers in the SSC siting area. Available data is shown in table 9, which presents analyses for radon-222 and uranium isotopes for groundwater samples collected in the SSC study area from four wells that produce from the glacial drift and three wells that are open to the shallow bedrock (Silurian and/or Maquoketa). Radon-222 concentrations are low and vary from 277 to 740 pCi/L. Dissolved uranium concentrations are also low and vary from 0.2 to 1.1 pCi/L for the combined concentration of uranium-238 plus uranium-234.

The general picture that emerges from analysis of the data is that the natural radioactivity in the siting area is normal for values that occur throughout the midwestern region of the United States.

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APPENDIX A

Glossary

Activity: The number of decay events or disintegrations per unit time

Alpha radiation: Radiation produced by radioactive decay which results in an emission of a particle with an atomic mass of 4 and a charge of +2 (helium ion). Radium-226 decays to radon-222 with the emission of a helium ion, for example. Alpha particles, despite having a low penetrating power, have a high radiation risk because of their mass and charge.

ARMS: Aerial Radiological Measuring Surveys sponsored nationwide by the U.S. Atomic Energy Commission from 1958 to 1963.

Becquerel (Bq): An amount of radioactivity equal to one disintegration per second. Becquerel is a unit in the System International (SI). The unit replaces the older term curie. One becquerel is equal to 0.037 pCi (picocuries).

Beta radiation: The decay process involving the conversion of a neutron into a proton in a nucleus which results in emission of beta particle with a charge of -1 (the electron). Lead-210 decays to bismuth-210 with the emission of an electron, for example. Beta particles are about 100 times more penetrating than alpha particles of the same energy.

Compton effect or scattering: When a medium energy photon (gamma ray) is released from a nucleus, it gives up part of its energy in collisions with bound electrons around the atom. The scattered photons will have a continuous energy spectrum since their energy depends on the scattering angle. If Compton scattering occurs, the resulting spectrum (using a NaI detector) will contain a very broad Compton peak which may obscure other superimposed peaks.

Curie (Ci): The amount of any radioactive substance required to produce 3.7×10^{10} disintegrations per second. Originally the curie represented the rate of decay of 1 gram of radium-226.

Dose: The quantity of energy from ionizing radiation absorbed by a living organism. Doses of ionizing radiation result from natural background radioactivity, occupational exposure, X-ray diagnosis, and release of radioactive material into the environment by humans.

Dose equivalent rate: The product of the absorbed dose, the quality factor (in rads), and any other modifying factors. The quality factor is 10 for alpha radiation, a mean of 5 for neutrons, and 1 for electrons and photons. Dose equivalent is expressed in rems and is related to the radiation risk.

Gamma radiation: Highly penetrating form of radiation arising from radioactive decay. Gamma radiation is electromagnetic radiation similar to X-rays in character, but higher in energy. Emission of gamma rays of discrete energies accompanies the radioactive decay of many isotopes. The decay of bismuth-214 to polonium-214 with the emission of a beta particle includes characteristic gamma rays that are utilized in spectral gamma logging.

Gray (Gy): The SI unit of absorbed dose. One gray equals one joule per kilogram. The rad is equal to 0.01 gray or 0.01 joule per kilogram.

Half life: The time required for the activity of a radioactive element to decay from any given initial value to half that value. The half life of radon-222 is 3.8 days, which means that a concentration of radon will decrease by one half every 3.8 days.

IDNS: Illinois Department of Nuclear Safety, established in 1980, regulates radioactive materials and monitors the levels of radioactivity in the environment. As the lead agency in Illinois dealing with the issue of indoor radon, IDNS established a Radon Hot Line (800-225-1245) for obtaining information about radon.

Micro- (μ): Prefix indicating 1 millionth, (10^{-6}). One microcurie (μCi)equals 3.7 x 10^{4} disintegrations per second.

Milli- (m): Prefix indicating 1 thousandth (10^{-3}). One millicurie (mCi) equals 3.7 a 10^{7} disintegrations per second.

Naturally occurring radioactive substances: All elements from natural sources and with atomic numbers greater than 83 (bismuth) are radioactive. The majority of these isotopes belong to the three radioactive series uranium-238, uranium-235 and thorium-228. (see figures 1 and 2). In addition to the series isotopes, there are 17 other naturally occurring radioactive isotope of which only potassium-40 and rubidium-87 are relatively abundant.

NCRP: National Council on Radiation Protection and Measurements is a nonprofit corporation chartered by Congress in 1964 to develop and disseminate information and recommendations about protection against radiation to the public. Information on prices and how to order publications may be obtained directly from NCRP Publications, 7910 Woodmont Ave, Suite 1016, Bethesda, Md. 20814.

Pico- (p): Prefix indicating one trillionth (10^{-12}). One picocurie equals 3.7 x 10^{-2} disintegrations per second.

Primary particles: All matter is formed from primary or elementary particles. Protons, neutrons and electrons are the most common elementary particles.

Primordial: Elements present during the formation of the earth. This term is often used with the radioactive elements, uranium and thorium.

Rad (Radiation Absorbed Dose): The energy delivered per unit mass of tissue by ionizing radiation. The rad equals 100 ergs of energy deposited in 1 gram of tissue.

Radon daughters: The short-lived radioactive isotopes formed as a result of decay of radon-222. They consist of polonium-218, lead-214, bismuth-214 and polonium-214. The radon daughter with the longest half-life is lead-214 with a half life of 26.8 minutes.

Rem (Radiation Equivalent Man): A unit for measuring the effects of radiation dose on the human body. A rem is equal to a rad multiplied by a relative biological effectiveness factor. For alpha radiation this factor is 10. For most common radiation sources the factor is 1 or 2.

Roentgen (R): A unit to express exposure to radiation from X-rays and gamma rays. One roentgen equals 2.58×10^{-4} coulomb per kilogram.

Secular equilibrium: The activities of all the short-lived decay products are equal to the activity of the very much longer-lived parent isotope, or the rate of production of a short-lived daughter isotope equals the rate of decay of the long-lived parent isotope.

Sievert (Sv): The SI unit for dose equivalent. One sievert equals 100 rem.

SI units: Systeme Internationale des Unites has adopted new names to be used in the field of ionizing radiation. The NCRP recommends the adoption of the new units by December 1989. The becquerel (Bq) replaces the older unit of activity, the curie (Ci). The term gray (Gy) has been adopted as a measure of dose, replacing the older term rad.

Working Level (WL): The concentration of radon decay products. The concentration of the short-lived radon daughters that has a potential alpha energy of 1.3×10^5 MeV per liter of air. A mixture of radon and its decay products having an activity of 100 pCi/L at equilibrium is equal to 1 WL.

For further information on radioactivity and radon: Hopke, 1987; Daintith, 1981; NCRP, 1975; NCRP 1984; NCRP,1985a; NCRP, 1985b; OECD 1985.

APPENDIX B

Gross alpha and beta radiation in groundwater from public water supply wells

Well no.	Location (Sec.-T-R)	Depth (ft)	Date	Gross Radiation Alpha (pCi/L)*	Gross Radiation Beta (pCi/L)*
Du Page County Sand and Gravel					
Bartlett #3	34-41N-9E	99	2/8/72	1±1	1±1
Du Page County Shallow Bedrock					
Bartlett #1	34-41N-9E	200	2/8/72	1±1	1±1
			8/21/73	0.2±1.4	9.2±2.8
Bartlett #2	34-41N-9E	200	2/8/72	1±1	1±1
			5/7/74	1.1±1.5	0.4±2.2
Naperville #10	1-38N-9E	223	10/1/73	1.3±1.6	3.5±1.9
			1/7/76	4.6±2.6	5.9±2.3
#11	23-38N-9E	210	1/7/76	4.0±2.8	3.2±2.5
#14	22-38N-9E	248	10/1/73	2.3±1.6	3.8±1.8
			1/7/76	1.4±1.6	3.8±1.8
#15	14-38N-9E	233	1/7/76	4.4±3.7	6.7±2.9
#17	9-38N-9E	205	11/11/74	1.6±1.4	3.2±1.9
			9/9/75	1.7±1.3	2.6±1.4
#18	9-38N-9E	290	11/11/74	4.3±2.4	2.5±1.9
#19	8-38N-9E	310	11/11/74	3.6±2.1	5.9±2.1
Winfield #2	13-39N-9E	335	10/1/73	0.2±2.4	3.8±2.6
			1/19/76	3.5±2.5	7.7±2.9
#4	13-39N-9E	348	4/20/72	1±2	0±2
			1/19/76	2.3±1.9	3.1±2.2
Warrenville#1	35-39N-9E	125	10/14/73	0.9±1.7	8.2±2.7
			1/7/76	2.1±2.3	2.0±2.6
#2	2-38N-9E	300	11/11/74	2.7±2.3	11.4±2.7
			7/16/75	2.1±1.8	16.1±2.7
Warrenville#3	35-39N-9E	256	4/17/72	1±2	1±2
			10/4/72	0.5±1.3	11.6±2.1
#4	34-39N-9E	365	11/11/74	0.9±1.4	8.2±2.3
#5	33-39N-9E	200	11/11/74	1.9±1.7	3.2±1.9
#6	36-39N-9E	178	10/4/73	0.7±1.2	5.2±1.6
			4/19/76	0.3±1.2	1.6±1.6
Warrenville (Albright St. Homeowners)					
#1	35-39N-9E	135	3/19/72	1±1	1±2
Warrenville (Roy St. Homeowners)					
#2	35-39N-9E	125	4/15/72	1±2	3±2

Well no.	Location (Sec.-T-R)	Depth (ft)	Date	Gross Radiation Alpha (pCi/L)*	Beta (pCi/L)*
Kendall County Sand and Gravel					
Plano #1	23-37N-6E	40	9/4/71	0±0	1±1
				0.9±1.3	4.1±1.7
#3	23-37N-6E	39.5	9/5/71	0±1	2±1
				0.1±0.7	2.5±1.4
#4	23-37N-6E	28	9/5/71	0±1	3±2
#5	23-37N-6E	40.7	8/2/71	0±1	3±2
			3/23/76	1.6±1.3	2.3±1.6
Yorkville #2	4-36N-7E	45	9/14/71	2±1	1±2
Kendall County Shallow Bedrock					
Marina Village #1	8-37N-8E	187	10/16/71	2±1	7±3
Kane County Sand and Gravel					
Carpentersville					
#3	15-42N-8E	76	11/14/73	0.6±1.0	3.6±1.5
			3/20/75	0.8±1.4	2.6±2.0
#4	14-42N-8E	175	9/8/71	0±1	1±2
#5	14-42N-8E	183	9/28/71	0±1	1±2
			3/17/75	0.8±1.3	1.5±1.8
#6	14-42N-8E	215	7/23/75	1.6±1.7	2.7±1.8
East Dundee #1	23-42N-8E	Spring	12/18/74	1.2±1.6	2.5±1.8
#2	23-42N-8E	72	11/13/73	0.9±1.4	3.6±1.8
#3	23-42N-8E	128	12/18/74	1.0±1.7	0.9±1.7
Elburn #2	5-39N-7E	153	9/13/71	1.0±1.0	0±2
Elgin North					
State Street	14-41N-8E	48	12/11/73	0.5±1.6	4.6±2.5
Ferson Creek	16-40N-7E	186	5/12/75	2.0±1.3	3.2±1.7
Maple Park #3	30-40N-6E	182	7/12/72	0.0±1.4	0.3±0.8
Montgomery #7	31-38N-8E	46	7/19/73	0.8±1.6	8.8±2.6
			12/23/75	2.7±2.3	7.9±2.2
St.Charles #7	28-40N-8E	175	3/31/75	0.5±1.4	3.3±2.0
St Charles					
Skyline #2	11-40N-8E	135	2/19/76	0.6±1.2	4.5±1.7
Sugar Grove#2	21-38N-7E	107	2/17/76	4.1±2.6	5.3±2.6
Sleepy Hollow	28-42N-8E	34	9/5/72	0.4±1.7	3.2±2.5
South Elgin#2	35-41N-8E	128	11/4/71	1±1	3±2
			8/26/74	1.8±1.6	0.4±2.3
South Elgin#3	35-41N-8E	112	12/15/71	1±1	1±2
			11/1/71	1±1	3±2
			11/4/71	1±1	2±2

Well no.	Location (Sec.-T-R)	Depth (ft)	Date	Gross Radiation Alpha (pCi/L)*	Gross Radiation Beta (pCi/L)*
South Elgin #3	35-41N-8E	112	11/29/71	1±1	0±0
			11/22/71	0±1	2±3
			11/29/71	0±0	1±3
			11/29/71	1±1	0±0
			12/2/71	0+2	5+2
			12/2/71	0±3	0±0
			12/3/71	0±1	2±2
			12/1/71	1±1	1±2
			12/8/71	1±1	0±2
			12/9/71	0±1	1±2
			12/9/71	1±1	1±2
			3/27/74	1.4±1.3	3.8±2.8
West Dundee#2	22-42N-8E	87	2/3/72	0±1	1±1
Kane County Shallow Bedrock					
Elgin Estates 1	28-41N-8E	300	2/12/76	0±1.1	2.6±1.8
Highland #1	15-40N-8E	152	3/23/76	2.3±1.6	2.2±1.6
Moecherville #2	26-38N-8E	180	12/3/73	2.0±1.4	2.3±1.7
#3	26-38N-8E	196	4/21/76	1.6±1.3	3.4±1.5
Montgomery #5	35-38N-8E	186	1/21/76	0±1	1±1
#6	31-38N-8E	160	12/23/75	3.1±3.5	4.8±2.0
Ogden Gardens #3	24-38N-8E	185	2/24/76	1.3±1.2	3.8±1.4
Park View #1	35-38N-8E	250	3/76	0.0±0.0	3.4±1.6
Prestbury #1	10-38N-7E	200	2/25/72	0.0±0.0	1±2
			11/8/73	1.1±1.1	2.5±1.9
			3/11/76	0.9±1.8	2.9±2.1
River Grange Lakes #1	9-40N-8E	180	3/76	1.8±1.5	5.0±1.6
Kane County Maquoketa Shale Group					
Bangs-Union Parker Sub #1	34-38N-8E	250	3/2/76	0.4±1.5	8.7±2.4
Lake Marian in the Woods #1	14-42N-8E	208	2/28/73	2.1±1.5	11.6±2.5
#2	11-42N-8E	251	2/28/73	1.3±1.3	6.8±2.2
Wermes #2	25-38N-8E	253	8/7/74	1.9±1.8	8.6±2.9

* Gross radiation analysis performed by the Illinois Environmental Protection Agency. The coefficient of variation is shown for each analytical value.